PROCEEDINGS OF THE INSTITUTE

REPORTS OF COUNCIL - OFFICIAL NOTICES

AUTUMN GENERAL MEETING, 1954

The AUTUMN GENERAL MEETING of THE IRON AND STEEL INSTITUTE was held on Wednesday and Thursday, 17th and 18th November, 1954, at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. The President, the Hon. R. G. LYTTELTON, was in the Chair.

Morning and afternoon sessions were held on both days, and buffet luncheons were provided in the Library of the Institute.

The Minutes of the previous Meeting, held in London on Wednesday and Thursday, 26th and 27th May, 1954, were taken as read and confirmed.

WELCOME TO MEMBERS AND VISITORS

The **President** (The Hon. R. G. Lyttelton), on behalf of the Council, offered a cordial welcome to all those attending the Meeting, and particularly to those from overseas.

OBITUARY

The **President** said that the Institute had suffered the loss of a number of members, and mentioned by name Mr. Seth S. Somers, who joined the Institute in 1896, Mr. James Campbell, who joined in 1897, Mr. George Baker, O.B.E., who joined in 1902, and Mr. J. C. W. Humfrey, who joined in 1903.

RECENT MEETINGS

The **President** referred to the fact that some very good meetings had been held since the Annual General Meeting. The most notable was that which took place in Sweden in June, 1954, and he wished to take the opportunity again to thank Jernkontoret and all others who had helped in the organization. Following the meeting some Members had paid a visit to Finland, and an account of this appeared in the November, 1954, issue of the *Journal*.

The Engineers Group had held a successful meeting in Consett, and the Council wished to record their thanks to Mr. Harold Boot of the Consett Iron Co., Ltd., and to Mr. B. Eliot Common of the Tyne Improvement Commission.

The third notable meeting had been arranged by the Institute in conjunction with the National Forgemasters' Association and the Chambre Syndicale de la Grosse Forge Française. Some interesting papers had been read on 12th and 13th October at the Offices of the Institute, and two or three days had been spent in Sheffield visiting works by invitation of the forgemasters there.

MEETINGS IN 1955

The **President** said that a full programme of meetings had been arranged for 1955. In addition to the Annual Meeting, on Wednesday and Thursday, 27th and 28th April, and the Autumn Meeting on Wednesday and Thursday, 16th and 17th November, in London, the Institute had been invited by the Lincolnshire Iron and Steel Institute to hold a special meeting in Scunthorpe from 12th to 14th October.

In June the Joint Metallurgical Societies' Meeting in Europe would be held. The programme in this country was from 1st to 7th June, and was being arranged jointly by The Iron and Steel Institute and the Institute of Metals. He was pleased to be able to announce that H.R.H. The Duke of Edinburgh had agreed to be Patron. The meeting would be continued at Düsseldorf, at Liège, and in France, concluding on 18th June. It was believed that this would be the first occasion on which members of the American Institute of Mining and Metallurgical Engineers and of the American Society for Metals would have joined in a meeting of this kind in Europe.

NOMINATION OF PRESIDENT

The **President** announced that the Council had nominated Sir Charles Bruce-Gardner, Bt., M.I.Mech.E., for election as President to take office at the Annual General Meeting in 1955 to serve for one year. The nomination had been carefully considered by the Council, and it was felt that a better choice could not have been made. Sir Charles was a distinguished man in the industry and had done great work for the Institute.

ANNOUNCEMENTS

Changes on the Council

The **Secretary** (Mr. K. Headlam-Morley) reported the following changes on the Council since the last General Meeting in May, 1954:

Vice-President—Mr. D. F. Campbell

Honorary Vice-Presidents—Mr. Berndt Grönblom, Mr. Evert Wijkander.

Member of Council—Mr. W. L. James

Honorary Members of Council (during their periods of office)—

Mr. W. M. Larke, Chairman of the Engineering Committee, in place of Mr. C. H. T. Williams, who remained on the Council in another capacity.

Mr. Henry M. Morgan, President of the Cleveland

Institution of Engineers, in place of Mr. F. Kennedy.

Mr. J. J. Beese, President of the Ebbw Vale Metallurgical Society, in place of Mr. A. W. Ellis.

Mr. C. E. Burrell, President of the Leeds Metallurgical Society, in place of Mr. H. D. Ward.

Lieut.-Commander G. W. Wells, President of the Lincolnshire Iron and Steel Institute, in place of Mr. W. L. James.

Mr. G. T. Callis, President of the Liverpool Metallurgical Society, in place of Mr. H. J. Miller.

Mr. C. I. F. Mackay, Chairman of the Newport and District Metallurgical Society, in place of Mr. T. G. Grey-Davies.

Professor H. O'Neill, President of the Swansea and District Metallurgical Society, in place of Mr. D. L. Blewett.

Retiring Members of Council

In accordance with Bye-law 10, the following were due to retire at the next Annual General Meeting and were eligible for re-election:

Vice-Presidents—Mr. G. H. Latham, Mr. J. Sinclair Kerr, and Dr. H. H. Burton.

Members of Council—Dr. J. W. Jenkin, Mr. W. F. Cartwright, Mr. F. H. Saniter, Mr. T. Jolly, and Mr. R. A. Hacking.

Andrew Carnegie Scholarships

The following awards had been made since the last General Meeting:

Mr. C. J. Ball (Queen's College, Cambridge): £410 to assist research on the plastic deformation of metals.

Mr. P. R. Vaughan Evans (University College, Swansea): £350 to assist research on the mechanical properties and internal stress of various strip steels after various isothermal treatments.

Mr. J. Wilcock (Liverpool University): £50 (second grant) to assist research on the influence of manganese, sulphur, and the sulphur/manganese ratio on the kinetics of first-stage graphitization.

MEETING IN FRANCE IN 1956

The **President** announced that the Council had accepted with pleasure a cordial invitation from the Chambre Syndicale de la Sidérurgie Française, in conjunction with the Société Française de la Métallurgie, to hold a meeting in Paris in 1956, probably in June. They greatly appreciated the invitation, and particularly the terms in which it had been couched.

ELECTION OF MEMBERS

Mr. **M. H. Bacon** and Dr. **W. H. Walker,** who had been appointed scrutineers of the ballot, reported that the following had been elected:

MEMBERS

Adams, William Henry, B.Sc., A.M.I.C.E. (Thornaby-on-Tees); **Allender,** Peter John, B.A., Ph.D. (Birmingham); **Alves,** Alfredo Carlos Taillet (Portugal); **Ammareller,** S., Dipl.Ing. (Germany); **Apps,** David Sydney, O.B.E., A.M.I.E.E. (Stafford); **Ash,** Arthur, L.I.M. (Glasgow); **Bacon,** Norwood Peter, Ph.D., B.Eng. (Rotherham); **Ballesteros,** Alfredo Gonzalez, M.Sc. (Mexico); **Boddey,** Ronald Frederick, B.Sc., A.R.I.C., A.I.M. (Birmingham); **Borstner,** Joze, Dipl.Ing. (Yugoslavia); **Bostandjis,** Harilaos Michael, B.Sc.(Eng.), M.I.C.E., D.R.T.C. (London); **Brandes,** G., Dipl.Ing. (Germany); **Brandi,** Hermann, Dr.mont., Dipl.Ing. (Germany); **Carlson,** Eugene Elmer, B.Met.Eng. (U.S.A.); **Carter,** G. T., M.A., B.Sc. (London); **Cecil,** Frank Eric, A.M.I.Mech.E. (Darlaston); **Chambeyron,** Jean (France); **Clary,** Philip Ebenezer (Dagenham); **Crawford,** Henderson Black, B.Sc., A.R.T.C. (Peterborough); **Darnell,** H., M.Eng., A.M.I.E.E. (Workington); **Das,** Badri Narayan (India); **Dew,** Clement Edgar, M.I.E.E., A.M.I.Mech.E. (Cardiff); **Douglas,** Llewellyn, D.Sc., M.I.Mech.E. (S. Africa); **Enroth,** Erik A. R. (Sweden); **Ezz,** Said Youssef, B.Sc. (London); **Fernbach,** Hans Rainer, M.I.E.E., Dipl.Eng. (Bournemouth); **Ferrán Vives,** Juan M. (Spain); **Finch,** Douglas Carver, B.Sc.Eng.(Met.) (Cowley); **Frame,** William M., B.Sc.(Mech.Eng.) (U.S.A.); **Fuller,** William Edward (Sheffield); **Gardiner,** John Howard (Sheffield); **Hackett,** Frederick John, B.Sc.(Eng.), M.I.Mech.E. (London); **Hagel,** William C., M.S., B.Met.E., Ph.D. (U.S.A.); **Hayton,** William Pearson, B.Sc. (Workington); **Herbert,** David Brudewell, B.Sc.(Ind.Met.) (Croydon); **Huddleston,** William (Rotherham); **Jansen,** Hermann, Dipl.rer.pol.techn. (Germany); **Jones,** Henry Ewart, B.Sc. (Scunthorpe); **Jowle,** William S. (Rotherham); **Klinck,** Ronald Woodard, M.A.Sc. (Canada); **Koerfer,** Ing. Walter (Sweden); **Koerfer,** Walter E. F., jun. (Sweden); **Krainer,** Helmut, Dr.mont. (Austria); **Kramer,** Irvin R., M.S., D.Eng. (U.S.A.); **Lunn,** Børge, M.Sc., Dr.techn., F.I.M. (Denmark); **McColl,** John Ramsay (Glasgow); **McCulloch,** A., A.M.I.E.E. (Australia); **McFetridge,** Daniel (Corby); **Masters,** John (West Bromwich); **Meredith,** James William (London); **Miller,** Laurence H. (Sheffield); **Milton,** Reginald John (Luton); **Molland,** Peter A. (London); **Molloy,** John A. (U.S.A.); **Moore,** Leslie Charles (Birmingham); **Noritake,** Terukuni (Japan); **Norlindh,** Sven Erik Malte (Sweden); **Pennington,** Peter George, A.M.I.Mech.E. (Middlesbrough); **Post,** Carl B., A.B., M.S., Ph.D. (U.S.A.); **Presern,** Alojzij, Dipl.Ing. (Yugoslavia); **Probyn,** F. E. C. (Ebbw Vale); **Redwood,** Richard, M.B.E. (Glasgow); **Rehngvist,** Nils Gösta (Sweden); **Rekar,** Prof. Cyril F., Dipl.Ing. (Yugoslavia); **Riddervold,** Hans Wilhelm (Norway); **Riley,** H. L., D.Sc., A.R.C.S., D.I.C., F.R.I.C. (Sheffield); **Roebling,** Ferdinand W., III., B.S. (U.S.A.); **Sachs,** Prof. George, Dr.Ing. (U.S.A.); **Sayer,** Cyril Eustace, B.Sc.(Eng.), A.M.I.C.E., A.M.I.E.E. (London); **Scholey,** Cyril, A.Met., A.I.M. (Sheffield); **Scriven,** Herbert, B.Sc.(Eng.), A.M.I.Mech.E. (Pontypool); **Sotlar,** Martin, Dipl.Ing. (Yugoslavia); **Spužic,** Muzafer, Dipl.Ing. (Yugoslavia); **Starkey,** Fergus (Oldham); **Steinroeder,** Fritz, Dr.rer.pol. (Germany); **Sutherland,** Alexander, A.M.I.E.E. (Edinburgh); **Temple,** Thomas William Jacques, A.M.I.E.E. (Middlesbrough); **Tinnion,** Ronald (Workington); **Trafford,** Harold Lewton, M.I.Mech.E., M.Inst.F. (Manchester); **Turnbull,** Herbert F., B.S.(Met.) (U.S.A.); **Wagman,** Frederick H., Ph.D. (U.S.A.); **Walsh,** Robert Laurie (Sheffield); **Walton,** Howard (Newcastle-on-Tyne); **Ward,** Raymond, B.S.(Met. Eng.), Ph.D. (U.S.A.); **Wilkinson,** H. N., B.Sc., G.I.Mech.E. (London); **Williams,** Edward John, L.I.M. (Shotton); **Winsor,** Reginald (Australia); **Worstenholme,** Geoffrey Michael, B.Sc. (Workington).

ASSOCIATE MEMBERS

Ardmongon, Saksit (Newcastle-on-Tyne); **Bowker,** Peter Howard (Newcastle-on-Tyne); **Bradbury,** Brian Tatterson (Sheffield); **Burlingame,** Richard D., M.S.(Met.Eng.) (U.S.A.); **Buxton,** Alan (Chesterfield); **Chakrabarti,** Sailendra Krishna (India); **Chotinuchit,** P. (Newcastle-on-Tyne); **Clarke,** Roger William (Bromsgrove); **Congleton,** John (Newcastle-on-Tyne); **Coulter,** Robert Smith (Glasgow); **Dixon,** Paul Richard, B.Met. (Sheffield); **Doldon,** Raymond (Sheffield); **Harper,** John Duncan (Cambridge); **Hedgecock,** Peter David, B.Sc., A.R.S.M. (Canada); **Henderson,** Leslie (Newcastle-on-Tyne); **Jones,** Dudley De Gruchy (Swansea); **Kumar,** Rajendra, M.Met., B.Sc.(Met.) (Sheffield); **Marshall,** David R. (Halifax); **Mordike,** Barry Leslie (Birmingham); **Morris,** John, B.Sc. (Ebbw Vale); **Parker,** Raymond (Wednesbury); **Parry,** Gareth Wyn (Swansea); **Piearcey,** Barry James (Newcastle-on-Tyne); **Pocock,** Nicholas J. B. (Cambridge); **Roberts,** David Anthony (Swansea); **Roberts,** Ernest Graham (Newcastle-on-Tyne); **Robinson,** James Frederick (Newcastle-on-Tyne); **Seal,** A. K., B.Sc.(Hons.), B.E.(Met.) (Sheffield); **Vernon,** P. N., B.Sc., A.R.S.M. (London); **Woodward,** Rodney (Newcastle-on-Tyne); **Worley,** Edward Michael (Cambridge).

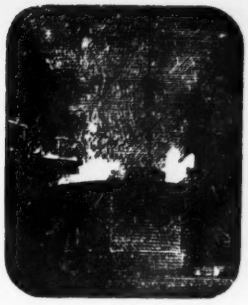
The **President** declared these candidates to be duly elected. They numbered 119, bringing the total Membership of the Institute to 4947.

PRESENTATION OF PAPERS

A list of the papers presented and discussed at the Autumn General Meeting was given in the October, 1954, issue of the *Journal*, p. 183.

PAPERS AND REPORTS ON
RESEARCH AND PRACTICE

METALLURGY · PLANT OPERATIONS · RESEARCH



Causes of Variable Creep Strength in Basic O.H. Carbon Steel

By W. E. Bardgett, B.Sc., F.I.M., and M. G. Gemmill, B.Sc., A.I.M.

SYNOPSIS

Creep and allied tests have been made on samples from 58 basic open-hearth casts of carbon steel in which the aluminium additions ranged from 1 to 2½ lb./ton. The steels were selected with the object of determining the causes of variation in their creep strength. The reaction of oxygen during steelmaking was examined for ten casts in relation to aluminium recovery; it has been shown that the soluble aluminium present in the steel is a paramount factor in the variable creep behaviour, whilst the McQuaid–Ehn grain size is also related to it. Further consideration of these features has led to the view that the creep resistance of any of the steels correlates directly with the aluminium nitride content, which in turn is related to the soluble aluminium content and grain-size characteristics of the steel. From a practical point of view it would appear that steels of good creep resistance can be obtained with aluminium additions of up to 1½ lb./ton, provided that mould additions of aluminium are limited. 1034

THE accumulation of creep test data has made it increasingly evident that much of the scatter of results obtained under similar testing conditions in mild steels can be attributed to variables in steel manufacture. Examination of such variables by one of the authors (W.E.B.) resulted in 1936 in a report[1] showing the marked effect of aluminium and silicon on the creep resistance of this quality of steel. This work was later published in the form of a contribution to the discussion of a paper by Glen.[2] Other research work, both in the U.S.A. and in the U.K., has probed into the causes of the considerable variations encountered in the creep resistance of steels of this type.[3–7] One factor which all this work has served to emphasize has been the detrimental effect of aluminium on the creep strength of low-carbon steels. It has been suggested that the adverse consequences of aluminium in steels made by the basic open-hearth (B.O.H.) process can be mitigated by increasing the manganese and silicon contents of the steels and that low residual oxygen content could be considered as a measure of large additions of aluminium and possibly resultant poor creep properties.

This paper presents the results of creep and allied tests made on samples from 58 B.O.H. casts of carbon steel. The steels had aluminium additions ranging from 1·0 to 2½ lb./ton, and to facilitate assessment they have been divided into four groups having additions of 1–1¼, 1⅞, 2, and 2¼–2½ lb. of aluminium per ton, respectively. The chemical composition and ladle and mould additions for the 58 steels investigated are given in Tables I*a–d*. Each steel was tested in the form of either 1-in. or 1½-in. dia. bar forged from rolled 4-in. round billet. The specimens were normalized from 920° C. The carbon contents ranged between 0·08% and 0·17%, the manganese between 0·34% and 0·56%, and the silicon between 0·06% and 0·14%.

EXPERIMENTAL PROCEDURE

All the creep tests were carried out at 450° C. and under a stress of 8·0 tons/sq. in. for a duration of 48 hr. in accordance with B.S.1271: 1945 (Proof test for creep quality, applicable to carbon steel boiler plate). In this test steels are assessed on the basis of the creep rate between the 24th and 48th hour. A creep rate of 50×10^{-6} in. per in. per hr. is selected as the limit for acceptance of this quality of steel. This test has been shown to correlate with the properties of steels of good and bad creep strength

Manuscript received 1st July, 1954.

Mr. Bardgett is Research Manager, The United Steel Companies, Ltd., and Mr. Gemmill is in charge of the High Temperature Metals Section at the Companies' Swinden Laboratories.

Table I

ANALYSES AND STEELMAKING ADDITIONS

Steel No.	Cast Analyses, %					Ladle Additions					Mould Addition: Al, oz./ton
	C	Mn	Si	S	P	Fe-Si, cwt.	Si-Mn, cwt.	Spiegel, cwt.	Fe-Mn, cwt.	Al, lb.	
(*a*) 1·0–1·5 lb./ton											
1	0·17	0·52	0·12	0·042	0·019	2·0	7·9	...	4·0	120	1–3
2	0·12	0·50	0·11	0·032	0·025	1·7	8·3	...	2·1	100	2
3	0·10	0·51	0·13	0·040	0·016	2·0	10·9	...	2·4	100	3
4	0·10	0·34	0·13	0·040	0·018	1·9	9·9	...	1·2	120	Nil
5	0·10	0·45	0·14	0·041	0·020	2·6	9·8	...	...	80	Nil
7	0·12	0·47	0·10	0·038	0·026	1·0	7·8	...	2·3	100	2–3
9	0·16	0·49	0·11	0·038	0·017	1·7	8·1	...	5·7	100	Nil
11	0·10	0·44	0·12	0·034	0·024	4·4	...	...	...	80	4–6
15	0·09	0·47	0·09	0·043	0·016	2·1	8·3	...	5·2	100	2–3
37	0·14	0·38	0·12	0·030	0·016	7·0	...	...	...	120	4–6
(*b*) 1⅞ lb./ton											
6	0·08	0·50	0·06	0·050	0·025	...	9·0	16·0	...	150	2–3
8	0·11	0·48	0·08	0·030	0·023	...	9·0	16·0	...	150	2–3
16	0·12	0·44	0·08	0·032	0·014	...	9·0	16·0	0·5	150	2–3
20	0·10	0·43	0·07	0·045	0·014	...	9·0	16·0	0·25	150	2–3
24	0·10	0·48	0·07	0·040	0·014	...	9·0	22·0	2·0	150	2
25	0·11	0·41	0·07	0·037	0·013	...	9·0	16·0	0·5	150	2
32	0·10	0·46	0·07	0·044	0·023	...	9·0	16·0	...	150	2–3
36	0·15	0·48	0·07	0·032	0·019	...	9·0	16·0	...	150	2
39	0·10	0·45	0·07	0·045	0·022	...	9·0	16·0	1·2	150	2–3
42	0·17	0·54	0·07	0·035	0·031	...	7·0	16·0	...	150	2–3
44	0·12	0·50	0·07	0·031	0·016	...	9·0	16·0	1·0	150	2–3
46	0·13	0·53	0·08	0·036	0·022	...	9·0	16·0	0·5	150	2
(*c*) 2 lb./ton											
10	0·11	0·47	0·07	0·028	0·020	...	8·5	...	...	160	2–3
12	0·10	0·51	0·07	0·028	0·019	...	9·5	...	1·5	160	2–3
14	0·11	0·51	0·07	0·028	0·019	...	9·5	...	2·0	160	2–3
18	0·09	0·52	0·07	0·028	0·019	...	9·5	...	1·5	160	2–3
19	0·09	0·39	0·06	0·037	0·023	...	9·5	...	...	160	2–3
21	0·07	0·47	0·08	0·034	0·009	...	9·0	...	0·5	160	2–3
22	0·11	0·45	0·09	0·024	0·032	...	9·5	...	0·5	160	2–4
23	0·08	0·46	0·07	0·029	0·019	...	9·5	...	0·25	160	2–3
27	0·11	0·49	0·08	0·038	0·024	...	...	...	9·0	160	2–4
28	0·09	0·43	0·07	0·041	0·031	...	6·0	...	...	160	2
29	0·11	0·40	0·09	0·040	0·017	...	7·6	...	...	160	Nil
30	0·12	0·44	0·09	0·040	0·018	1·0	6·5	...	...	160	2–3
31	0·12	0·48	0·08	0·032	0·022	...	9·0	...	...	160	2
40	0·12	0·50	0·07	0·037	0·030	...	9·5	...	...	160	2–3
47	0·15	0·56	0·10	0·026	0·017	...	9·5	...	0·25	160	2–3
52	0·12	0·53	0·07	0·029	0·024	...	9·5	...	...	160	2–3
(*d*) 2¼–2½ lb./ton											
13	0·11	0·46	0·09	0·052	0·016	...	10·9	...	3·1	180	2–3
17	0·11	0·51	0·09	0·039	0·019	...	11·5	...	1·4	180	1
26	0·10	0·41	0·09	0·035	0·022	...	10·9	...	0·4	180	2–3
33	0·10	0·52	0·09	0·031	0·014	...	11·3	...	...	180	Nil
34	0·15	0·52	0·11	0·029	0·027	...	10·5	...	...	180	1–2
35	0·15	0·51	0·07	0·037	0·020	...	11·5	...	...	180	0–2
38	0·12	0·43	0·07	0·036	0·017	1·74	...	...	...	185	4–6
41	0·10	0·55	0·09	0·034	0·016	...	11·9	...	...	180	2–3
43	0·12	0·46	0·08	0·036	0·017	...	10·6	...	...	180	2–3
45	0·10	0·45	0·09	0·033	0·014	...	11·3	...	...	180	4–6
48	0·10	0·38	0·09	0·034	0·019	...	8·3	...	...	180	2–3
49	0·13	0·46	0·09	0·036	0·017	...	9·3	...	...	180	2–3
50	0·14	0·48	0·08	0·036	0·021	...	11·7	...	1·5	180	1–2
51	0·10	0·36	0·06	0·031	0·023	...	7·4	...	...	180	2–3
53	0·13	0·45	0·10	0·033	0·019	...	11·3	...	...	180	2–3
54	0·12	0·46	0·08	0·034	0·013	...	10·8	...	...	180	4–6
55	0·09	0·50	0·08	0·030	0·017	...	10·4	...	...	180	2–3
56	0·13	0·45	0·09	0·045	0·018	...	10·7	...	1·0	180	2
57	0·11	0·37	0·07	0·036	0·019	3·5	...	...	...	200	4–6
58	0·14	0·37	0·12	0·033	0·017	3·5	...	...	...	200	4–6

under conditions of stress and temperature akin to those met in service.[8]

RESULTS

Tables II*a–d* give the creep data for the 58 steels examined, the results being considered in four groups as mentioned above. Within each group the steels have been arranged in order of decreasing creep resistance. These Tables also include data on aluminium additions, grain size, and, in certain cases, oxygen contents of the steels at various stages in their manufacture.

The steels considered were chosen with the deliberate object of determining the cause of the variation in creep strength and in this way of controlling it. Interrelated factors having a possible influence on the creep strength of these steels include the grain size and the soluble aluminium content. Since variation in the latter may be associated with the deoxidation conditions, an attempt was made, using ten B.O.H. casts, to examine the reaction of oxygen during refining, tapping, and teeming of this type of steel. It appeared from this work that the aluminium recovery could not be directly correlated with any

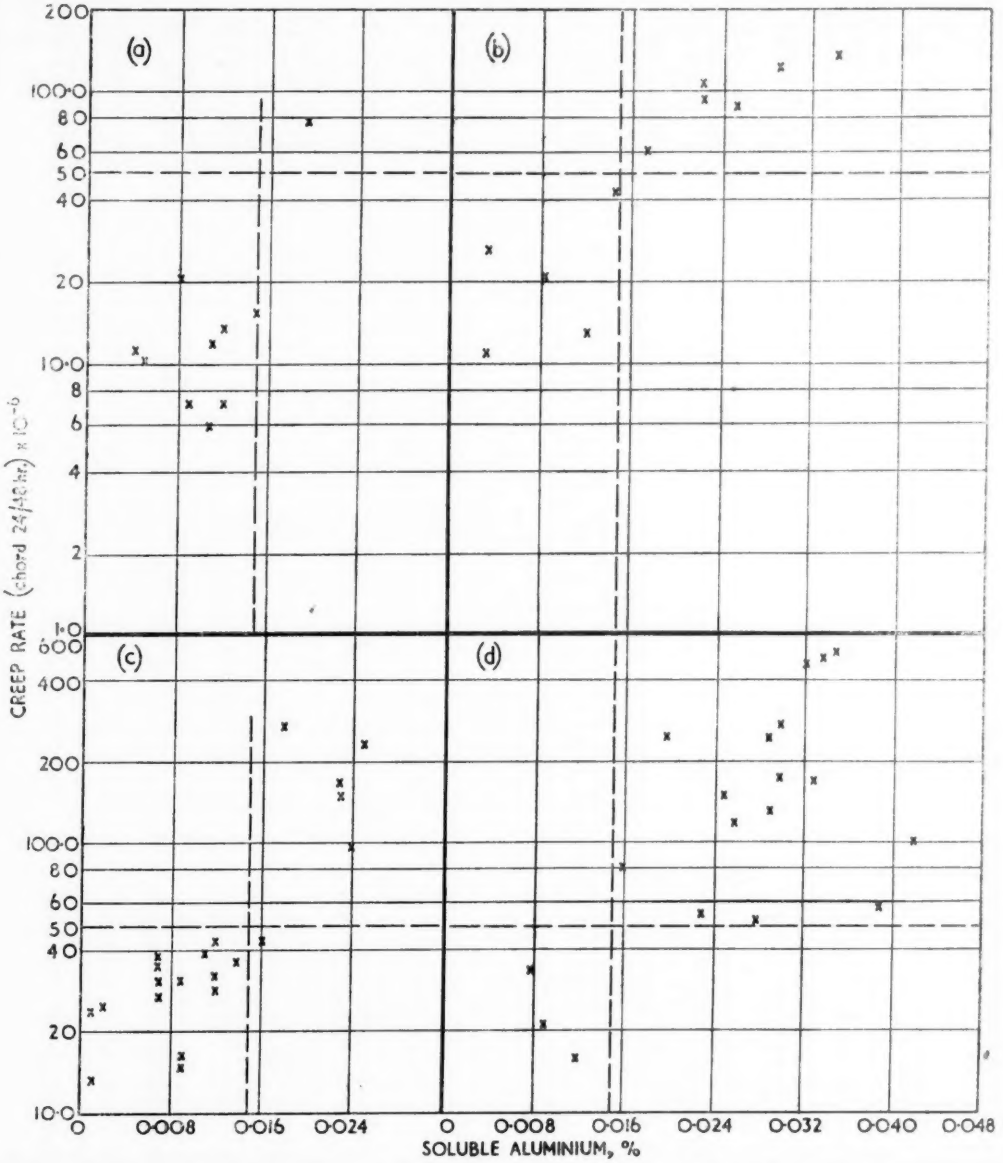


Fig. 1—Soluble-aluminium/creep-rate relationship; Al ladle additions: (*a*) 80–120 lb., (*b*) 150 lb., (*c*) 160 lb., (*d*) 180–200 lb.

Table II

CREEP PROPERTIES, GRAIN SIZE, AND ALUMINIUM ADDITIONS

Steel No.	B.S. 1271 Creep Test				Grain Size		Aluminium								Bar or Billet Oxygen, %
	Plastic Loading Strain, %	Creep Strain After Loading 48 hr., %	Total Plastic Strain (48 hr.), %	Creep Rate, $\times 10^{-4}$ strain/hr. (Chord 24–48 hr.)	McQuaid–Ehn	Ferritic	Addition per ton			In Steel, %			Recovery, %		
							Ladle, lb.	Mould, oz.	Final, lb.	Insol. Al_2O_3	Soluble	Total	As Total Al	As Soluble Al	
(*a*) 1·0–1·5 lb./ton															
1	0·043	0·108	0·151	5·8	1–2 (*C*)	...	1·5	1–3	1·55	0·007	0·011	0·015	22	16	...
2	0·086	0·139	0·225	7·0	2, 3 (*C*)	...	1·2½	2	1·36	0·007	0·012	0·016	26	20	...
3	0·097	0·134	0·231	7·0	2, 3 (*C*)	...	1·2½	3	1·41	0·014	0·009	0·016	25	14	...
4	0·064	0·158	0·222	10·1	2, 3 (*C*)	...	1·5	Nil	1·32	0·002	0·005	0·006	10	9	...
5	0·109	0·202	0·311	11·0	1, 2 (*C*)	...	1·0	Nil	0·92	0·001	0·004	0·005	12	10	...
7	0·071	0·225	0·296	11·8	2, 3 (*C*)	...	1·2½	2–3	1·32	0·011	0·011	0·017	29	19	...
9	0·078	0·185	0·263	13·3	1, 5–7 (*M*)	...	1·2½	Nil	1·21	0·014	0·012	0·019	35	22	...
11	0·101	0·222	0·323	15·0	,,	...	1·0	4–6	1·20	0·014	0·015	0·022	41	28	...
15	0·187	0·296	0·483	20·0	1, 4 (*C*)	...	1·2½	2–3	1·40	0·005	0·008	0·011	18	13	...
37	0·122	0·980	1·102	76·0	6, 8 (*F*)	...	1·5	4–6	1·80	0·020	0·019	0·029	36	24	...
(*b*) 1⅞ lb./ton															
6	0·117	0·150	0·267	11·0	2, 3 (*C*)	6	1⅞	2–3	2·00	0·005	0·003	0·005	6	3	0·008
8	0·025	0·187	0·212	12·8	1 8 (*M*)	6, 7	,,	,,	1·95	0·002	0·012	0·013	14	13	0·003₂
16	0·101	0·292	0·393	21·1	1, 3 (*C*)	,,	,,	,,	1·99	0·003	0·008	0·010	11	8	,,
20	0·072	0·323	0·395	26·6	3, 4 (*C*)	6	,,	,,	,,	0·007	0·003	0·007	7	3	0·003
24	0·114	0·399	0·513	30·9	1, 4–6 (*M*)	6, 7	,,	2	1·95	0·008	0·004	0·008	9	5	...
25	0·072	0·412	0·484	31·0	2, 3 (*C*)	6	,,	,,	2·00	0·002	0·004	0·005	6	4	0·002₂
32	0·112	0·436	0·548	43·2	5, 6 (*M*)	...	,,	2–3	2·08	,,	0·014	0·015	17	14	0·003
32	0·082	0·690	0·772	93·5	6, 7 (*F*)	...	,,	,,	,,	0·003	0·022	0·023	25	22	0·002₂
36	0·146	0·148	1·294	61·8	6, 8 (*F*)	6, 7	,,	2	1·95	0·002	0·017	0·018	20	17	,,
39	0·071	0·822	0·893	86·6	5, 7 (*F*)	6	,,	2–3	2·07	,,	0·025	0·026	29	25	,,
42	0·077	0·650	0·727	108·1	1, 6, 8 (*M*)	6, 7	,,	,,	2·20	0·003	0·022	0·024	25	22	,,
44	0·118	1·065	1·183	121·4	,,	,,	,,	,,	1·97	0·002	0·029	0·030	33	32	...
46	0·099	1·085	1·184	133·8	,,	,,	,,	2	2·04	0·003	0·034	0·035	39	37	...
(*c*) 2 lb./ton															
10	0·071	0·184	0·255	13·3	1, 4, 5 (*M*)	...	2·0	2–3	2·09	0·004	0·001	0·003	3	1	...
12	0·077	0·188	0·265	15·0	2, 4, 6, 7 (*M*)	...	,,	,,	2·07	0·002	0·009	0·010	11	10	...
14	0·110	0·234	0·344	16·5	2, 5, 6 (*M*)	...	,,	,,	2·06	,,	,,	,,	,,	,,	...
18	0·144	0·332	0·476	23·5	2, 5 (*M*)	...	,,	,,	2·04	,,	0·001	0·002	2	1	...
19	0·122	0·327	0·449	25·1	2, 4, 5 (*M*)	...	,,	,,	2·00	0·004	0·002	0·004	4	2	...
21	0·226	0·356	0·582	26·8	1, 4 (*C*)	...	,,	,,	1·99	0·002	0·007	0·008	8	7	0·004
21	0·278	0·399	0·677	30·0	2, 3 (*C*)	...	,,	,,	,,	,,	,,	,,	,,	,,	0·004*
22	0·143	0·336	0·479	28·5	1, 4 (*C*)	...	,,	2–4	2·02	0·004	0·012	0·014	14	12	0·009*
22	0·116	0·368	0·484	32·0	1, 3 (*C*)	...	,,	,,	,,	,,	,,	,,	,,	,,	...
23	0·200	0·450	0·650	30·4	2, 3, 4, 8 (*M*)	...	,,	2–3	2·04	,,	0·009	0·011	11	9	...
27	0·118	0·402	0·520	34·7	1, 7 (*M*)	...	,,	2–4	2·09	0·002	0·007	0·008	9	7	...
28	0·160	0·442	0·602	36·0	5, 7 (*F*)	...	,,	2	1·98	,,	0·014	0·015	15	14	...
28	0·126	0·442	0·568	42·6	5, 8 (*F*)	...	,,	,,	,,	,,	0·012	0·013	13	12	...
29	0·178	0·487	0·665	37·0	2, 6, 7 (*M*)	...	,,	Nil	1·82	,,	0·007	0·008	10	9	...
30	0·157	0·420	0·577	39·0	4, 6 (*M*)	...	,,	2–3	2·08	0·004	0·011	0·013	13	11	0·003
30	0·190	1·845	2·035	258·7	,,	...	,,	,,	,,	0·002	0·018	0·019	20	19	...
31	0·178	0·518	0·696	42·5	7, 8 (*F*)	...	,,	2	1·96	,,	0·016	0·017	20	16	...
40	0·114	0·883	0·997	96·1	,,	...	,,	2–3	2·09	,,	0·024	0·025	27	24	...
47	0·101	0·131	1·232	147·5	6, 7 (*F*)	...	,,	,,	1·98	0·004	0·023	0·025	28	26	...
47	0·085	1·245	1·330	162·8	5, 8 (*F*)	...	,,	,,	,,	,,	,,	,,	,,	,,	0·002
52	0·190	1·647	1·837	227·7	2, 3, 8 (*M*)	...	,,	,,	2·03	,,	0·025	0·027	30	27	...
(*d*) 2¼–2½ lb./ton															
13	0·163	0·247	0·410	16·0	1, 3 (*C*)	...	2¼	2–3	2·39	0·010	0·012	0·017	16	11	...
17	0·151	0·305	0·456	21·8	6, 7 (*F*)	...	,,	1	2·29	0·007	0·009	0·013	13	9	...
26	0·192	0·408	0·600	34 0	4, 6 (*M*)	...	,,	2–3	2 35	0·003	0·008	0·010	10	8	...
33	0·121	0·503	0·624	51·0	5, 7 (*F*)	...	,,	Nil	2·27	0·001	0·028	0 029	29	27	...
34	0·095	0·487	0·582	52·7	7, 8 (*F*)	...	,,	1–2	2·18	0·017	0·039	0·048	49	39	...
35	0 132	0·500	0·632	54 0	5, 7 (*F*)	...	,,	0 2	2·41	0·006	0·023	0·026	24	21	...
38	0·127	0·760	0·887	82 0	7, 8 (*F*)	...	2·3	4–6	2·60	0·002	0 016	0·017	15	14	...
41	0·075	0 695	0·770	98·0	6, 8 (*F*)	...	2¼	2–3	2 54	0·001	0·042	0·043	38	37	...
43	0·197	0 927	1 124	118·6	,,	...	,,	,,	2·28	0·002	0·026	0·027	27	26	...
45	0·225	1·560	1·815	131·0	,,	...	,,	4–6	2·59	0·004	0·029	0·031	,,	25	...
48	0·300	1·590	1·890	148·0	6, 7 (*F*)	...	,,	2–3	2·29	0·013	0·025	0·032	31	,,	...
49	0·176	1·375	1·551	160·0	,,	...	,,	,,	,,	0·009	0·033	0·038	37	33	...
50	0·200	1·193	1·393	165·0	5, 7 (*F*)	...	,,	1–2	2·43	0 006	0·033	0·036	33	30	...
51	0·257	1·352	1·609	171 0	6, 7 (*F*)	...	,,	2–3	2 14	0·008	0·030	0·034	36	31	...
53	0 264	1·910	2·174	240 0	,,	...	,,	,,	2·43	0·006	0·029	0·032	29	27	...
54	0·160	1·720	1 880	245·0	6, 8 (*F*)	...	,,	4–6	2·48	0 003	0·020	0·022	20	18	...
55	0 324	2·592	2·916	269·0	,,	...	,,	2–3	2·25	0 007	0·030	0·034	34	30	...
56	0·319	2·970	3·289	443·0	5, 6 (*F*)	...	,,	2	2 28	0·004	0·032	0·034	33	32	...
57	...	3·47†	3·47	449·0	7, 8 (*F*)	...	2¼	4–6	2·80	0·003	0·034	0·036	29	27	...
58	...	3·84†	3·84	496·0	6, 8 (*F*)	...	,,	,,	,,	0·014	0·035	0·042	34	28	...

* Fractional vacuum-fusion results available (*see* Table III) † Includes plastic loading strain

single factor, but there were three contributory factors:

(*a*) Reaction with dissolved oxygen in the bath at tapping
(*b*) Reaction with slag entering the ladle with the metal
(*c*) Reaction with atmospheric oxygen during tapping and teeming.

All these are subject to such variation that there appears to be little prospect of controlling the soluble aluminium by means of the deoxidation treatment. The tapping percentage of carbon and the FeO contents of the slag, which are indicators of reactive oxygen at tapping, showed no correlation with creep resistance.

Steels Having 1–1·5 lb. of Al per ton Ladle Addition

The data on the ten steels in this division are presented in Tables I*a* and II*a*. The relationship between the soluble aluminium content and creep rate of the ten steels in this group is given in Fig. 1*a*. Grids have been drawn at a creep rate of 50×10^{-6} and at a soluble aluminium content of 0·015%. The former represents the limit of acceptance by the B.S.1271 test; it will be noted that any steel containing 0·015% of soluble aluminium or less falls below the horizontal grid line and that the only steel containing more than 0·015% of soluble aluminium lies above it.

Of these ten steels, seven had a coarse McQuaid–Ehn grain size (4 or less) and creep rates ranging from $5{\cdot}8 \times 10^{-6}$ to 20×10^{-6}, two were of mixed grain size and had creep rates of $13{\cdot}3 \times 10^{-6}$ and $15{\cdot}0 \times 10^{-6}$, and one was of fine grain size (5 or more), having a creep rate of $76{\cdot}0 \times 10^{-6}$. The latter would not have passed the B.S.1271 test. These results suggest that with aluminium additions of up to 1¼ lb./ton to the ladle, adequate creep properties would be obtained with normal mould additions, but that at the 1½-lb./ton level, poor properties might occur if a rather large mould addition of aluminium was made and the steel was not highly oxidized.

Steels Having 1⅞ lb. of Al per ton Ladle Addition

The results for the 12 steels in this group are given in Tables I*b* and II*b* and the relationship between soluble aluminium and creep rate is shown in Fig. 1*b*. Of the 12 steels examined, four were coarse-grained and had creep rates ranging from $11{\cdot}0 \times 10^{-6}$ to $31{\cdot}0 \times 10^{-6}$, six were mixed-grained and had creep rates ranging from $12{\cdot}8 \times 10^{-6}$ to $133{\cdot}8 \times 10^{-6}$, and two were fine-grained, having creep rates of $61{\cdot}8 \times 10^{-6}$ and $86{\cdot}6 \times 10^{-6}$. Both the latter and three of the mixed-grain steels would have failed the B.S.1271 test. As indicated in Fig. 1*b*, all the steels having 0·015% or less of soluble aluminium had rates of creep less than 50×10^{-6} and all those with >0·015% of soluble aluminium had rates greater than 50×10^{-6}.

The creep behaviour of steel 32 is of especial interest. The initial test made showed it to have a creep rate of $43{\cdot}2 \times 10^{-6}$, a soluble aluminium content of 0·014%, and a mixed grain size (5, 6). A specimen taken from further along the same bar had a creep rate of $93{\cdot}5 \times 10^{-6}$, a soluble aluminium content of 0·022%, and a fine grain size (6, 7). This result is an interesting confirmation of the role played by aluminium, illustrating how critical its effect can be on both grain size and creep strength. Vacuum-fusion oxygen determinations were made on nine of these steels, including values obtained for each creep specimen of steel 32. Apart from steel 6 (0·008% O_2) the values were between $0{\cdot}002_5$ and $0{\cdot}003_5$%; it is thus apparent that the residual oxygen content bears no relationship to the creep properties.

In summary, with aluminium additions of 1⅞ lb./ton to the ladle, adequate creep strength will be dependent on a degree of deoxidation such that the soluble aluminium content does not exceed 0·015%, but in a steel which is borderline the possibility exists that

Table III

OXYGEN CONTENT AND CREEP RESISTANCE

Steel No.	Billet Sample	Fractional Vacuum-Fusion Results				Creep Rate, $\times 10^{-6}$ strain/hr. (B.S.1271)	McQuaid–Ehn Grain Size	Soluble Aluminium, %
		O_2 as FeO.MnO	O_2 as SiO_2	O_2 as Al_2O_3	Total O_2, %			
21	1	...	...	...	0·004	26·8	1, 4 (*C*)	0·007
	2	Nil	0·004	Nil	0·004	30·0	2, 3 (*C*)	0·007
22	1	...	...	...	...	32·0	1, 3 (*C*)	0·012
	2	0·003	0·005	0·001	0·009	28·5	1, 4 (*C*)	0·012
28	1	...	...	...	...	36·0	5, 7 (*F*)	0·014
	2	...	...	...	...	42·6	5, 8 (*F*)	0·012
	6	Nil	0·002	0·001	0·003	...	5, 7 (*F*)	0·010
30	20	...	...	0·001*	...	258·7	4, 6 (*M*)	0·018
	22	...	...	0·002	0·003	39·0	4, 6 (*M*)	0·011
47	1	...	...	0·002*	0·002	162·8	5, 8 (*F*)	0·023
	2	...	...	0·002*	...	147·5	6, 7 (*F*)	0·023

* Chemically determined

aluminium segregation could cause significant variation in the properties.

Steels Having 2 lb. of Al per ton Ladle Addition

The data for the 16 steels in this group are given in Tables Ic and IIc and the relationship between soluble aluminium and creep rate in Fig. 1*c*. Two of the 16 steels were coarse-grained and had creep rates of $26{\cdot}8 \times 10^{-6}$ and $32{\cdot}0 \times 10^{-6}$; ten were mixed-grained and had rates ranging between $13{\cdot}3 \times 10^{-6}$ and $227{\cdot}7 \times 10^{-6}$, and four were fine-grained, having rates between $36{\cdot}0 \times 10^{-6}$ and $162{\cdot}8 \times 10^{-6}$. Two of the fine-grained steels and one mixed-grain steel would not have passed the B.S.1271 test, whilst one steel of mixed grain (No. 30) showed creep rates of 39×10^{-6} and $258{\cdot}7 \times 10^{-6}$ for separate specimens. This steel and steels 21, 22, 28, and 47 were five of the ten steels examined primarily from the deoxidation aspect and mentioned earlier in the paper.

The fractional vacuum-fusion results determined on billet samples of steels 21, 22, and 28 are given in Table III, together with total oxygen values (vacuum-fusion) for steels 30 and 47. The oxygen in steels 21, 28, 30, and 47 is very low and occurs chiefly as alumina; the oxygen of steel 22 is rather higher and occurs mainly as manganese silicate. There is no indication of any relationship between total oxygen content and creep resistance.

Therefore, with an aluminium addition of 2 lb./ton to the ladle, similar conclusions may be drawn as from the rather similar previous group of steels. Of the 20 tests made in this series, the five showing creep rates in excess of 50×10^{-6} had soluble aluminium contents between 0·018% and 0·025%, whilst of the 16 steels having creep rates below 50×10^{-6} only one (steel 31) had a soluble aluminium content >0·015%, namely 0·016%.

Steels Having 2¼–2⅞ lb. of Al per ton Ladle Addition

The data for the 20 steels in this group are given in Tables I*d* and II*d* and the soluble-aluminium/creep-rate relationship in Fig. 1*d*.

Eighteen of the steels were fine-grained and had rates of creep between $21{\cdot}8 \times 10^{-6}$ and 496×10^{-6}, one was of mixed grain with a creep rate of $34{\cdot}0 \times 10^{-6}$, and one of coarse grain, creep rate $16{\cdot}0 \times 10^{-6}$. Only the latter two and one of the 18 fine-grain steels would have passed the B.S.1271 test, and these had soluble aluminium contents of between 0·008% and 0·012%; the other 17 steels had soluble aluminium contents between 0·016% and 0·042%. With this level of aluminium addition (2¼-2⅞ lb./ton) to the ladle it is obvious that only a few steels will possess adequate creep properties, based on the B.S.1271 criterion.

DISCUSSION OF RESULTS

Reviewing the information which has been obtained, it is clear that the soluble aluminium present in these B.O.H. steels is a paramount factor in the variable creep behaviour. It is of interest to note that this is particularly pronounced when considering separately the steels having aluminium additions of 1⅞ and 2 lb./ton to the ladle, and is not quite so evident in the groups with lower (1–1½ lb./ton), and higher (2¼ and 2½ lb./ton) aluminium levels. It is possible that up to 1½ lb./ton the amount of aluminium added is still slightly short of that required to ensure thorough deoxidation and this results, in the case of a normally oxidized melt, in a coarse-grained steel. This non-equilibrium condition might account for the less direct relationship between creep resistance and soluble aluminium content. With aluminium additions of 1⅞ and 2 lb./ton the relationship is more definite. With aluminium additions above 2 lb./ton, there is again no relationship and the reason for this remains to be determined.

Two factors, soluble aluminium content and McQuaid–Ehn grain size, have been found to be associated with one another and with the creep resistance, although the relationship is much more precise with the former. It is clear that the value of 0·015% soluble aluminium is critical in that above this amount creep is poor and the grain sizes are mixed or fine, whilst below this amount creep resistance is good and the grain size is coarse or mixed. Owing to our inability strictly to control the residual aluminium by means of the deoxidation process in steelmaking, it would not be possible to work very close to the figure of 0·015%. The B.S.1271 test provides a very similar division of the steels in relation

Table IV

INFLUENCE OF ALUMINIUM NITRIDE CONTENT ON PROPERTIES OF STEEL 47

Heat-Treatment	Aluminium, %			Soluble Al less Al present as AlN	Grain Size			Creep Rate, × 10⁻⁶ strain/hr. (Chord 24–48 hr.)
	Soluble*	Insoluble	AlN		McQuaid–Ehn	Ferritic		
						A.S.T.M.	Grain Dia., in.	
920° C., A.C.	0·023	0·002	0·0064	0·017	5–8	...	...	162·8
940° C., A.C.	,,	,,	0·0044	0·018	6–8	6–7	0·0009	60·6
960° C., A.C.	,,	,,	0·0041	0·019	6–7, 8	7, 8	0·0008	54·2
980° C., A.C.	,,	,,	0·0042	0·019	6–7	6–7	0·0009	44·6
1000° C., A.C.	,,	,,	0·0021	0·021	5–7, mainly 7	5–6, 4	0·0012	6·8
1020° C., A.C.	,,	,,	0·0017	0·021	5–6, 7	4–5, 6	0·0014	6·4
1050° C., A.C.	,,	,,	0·0004	0·023	...	...	...	5·0
1050° C., W.Q.	,,	,,	0·0004	0·023	3–8	...	...	11·4

* Constant for each sample

to creep resistance to the 0·015% soluble aluminium criterion, thereby confirming its general usefulness as a short-time selective test.

A convenient but less precise method of distinguishing between the various types of steel is the McQuaid–Ehn grain size. Of the 58 specimens tested, 14 were coarse-grained, containing up to 0·012% of residual aluminium, none failing in the B.S.1271 test; 19 were mixed-grain, residual aluminium ranging between 0·001% and 0·034%, four specimens (19%) failing the B.S.1271 test; and 25 were fine-grained with 0·009–0·042% of residual aluminium, 22 (80%) failing the B.S.1271 test. Although a coarse-grain steel always possesses a high standard of creep resistance, mixed-grain or even some fine-grain steels may also be of a high standard.

The soluble aluminium content of these steels contains a proportion of aluminium, combined as aluminium nitride. The development of a method of analysis for determination of this nitride[9] has shown that the amount present in a steel can be varied by heat-treatment: this has been illustrated by the recent work of Leslie *et al.*,[10] which has outlined in some detail the nature of AlN solution and precipitation in steels of this type. The temperature at which the AlN is finally dissolved in the austenite is a function of both the aluminium and nitrogen contents of the steel.

A more detailed examination of the role of AlN in relation to the creep strength has been made in the case of the fine-grained steel 47 on samples air-cooled from 940°, 960°, 980°, 1000°, 1020°, and 1050° C. and one sample water-quenched from 1050° C. The aluminium present as AlN was determined for each specimen, as was the creep resistance using the B.S.1271 test. The results obtained are given in Table IV, whilst Fig. 2 shows the relationship between creep rates and aluminium present as AlN. The soluble aluminium content was, of course, the same for all the samples.

From the data derived for steel 47, complete solution of the AlN in the austenite would occur at about 1080° C.

The McQuaid–Ehn grain size determination, which has been shown to correlate very well with the creep properties of steels normalized from 920° C., is carried out by heating the steel for 8 hr. at 927° C. The

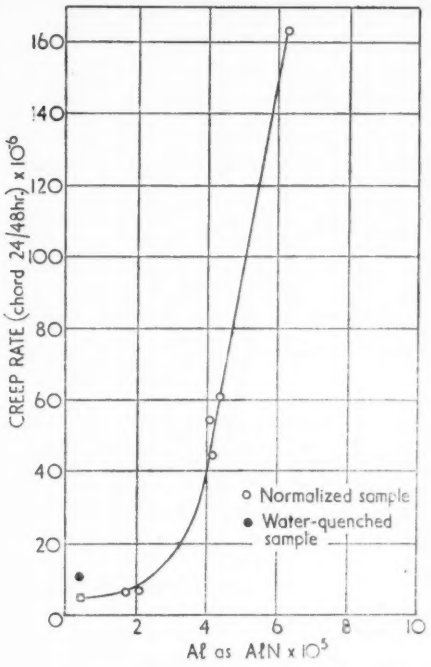


Fig. 2—Aluminium-nitride/creep-rate relationship (steel 47)

reason for this agreement is probably to be found in the like amounts of AlN present at 920° and 927° C. in any one steel. It is of interest in this connection to note the slight coarsening shown by the McQuaid–Ehn tests (Table IV) made on the specimens of steel 47 normalized from 1000° and 1020° C. The ferritic grain size is also influenced, being 0·0008–0·0009 in. grain dia. for the samples normalized at 940°, 960°, and 980° C., and 0·0012 and 0·0014 in., respectively, for normalizing temperatures of 1000° and 1020° C. The amount of AlN present may be associated with the grain size, both McQuaid–Ehn and actual.

Aluminium nitride analyses have been made on five steels (21, 30, 47, 52, and 57 in Table V) in one

Table V

INFLUENCE OF ALUMINIUM NITRIDE ON GRAIN SIZE AND CREEP RESISTANCE

Steel No.	Heat-Treatment	Aluminium, %			Soluble Al less Al present as AlN	McQuaid–Ehn Grain Size	Creep Rate × 10^{-4} strain/hr. (Chord 24–48 hr.)
		Soluble	Insoluble	AlN			
21	920° C., A.C.	0·007	0·001	Nil	0·007	2, 3 (*C*)	30·0
30	920° C., A.C.	0·011	0·002	0·0017	0·009	4, 6 (*M*)	39·0
		0·018	0·001	0·0042	0·014	4, 6 (*M*)	258·7
47	920° C., A.C.	0·023	0·002	0·0064	0·017	5, 8 (*F*)	162·8
52	920° C., A.C.	0·025	0·002	0·0044	0·020	2, 3, 8 (*M*)	227·7
57	920° C., A.C.	0·028	0·002	0·0058	0·022	7, 8 (*F*)	449·0

Table VI

EFFECT OF NORMALIZING TEMPERATURE ON CREEP RESISTANCE

Steel No.	Soluble Al, %	Heat-Treatment	Creep Rate × 10^{-4} strain/hr. (Chord 24–48 hr.)	Grain Coarsening Characteristics	Heat-Treatments*	Creep Rate × 10^{-4} strain/hr. (Chord 24–48 hr.)
20	0·003	920° C., A.C.	26·6	Slight coarsening above 1000° C.	950° C., A.C.	31·8
25	0·004	,,	31·0	,,	1000° C., A.C.	40·2
44	0·029	,,	121·4	Marked coarsening 950–1050° C.	1030° C., A.C.	42·3
46	0·034	,,	133·8	,,	1060° C., A.C.	8·1

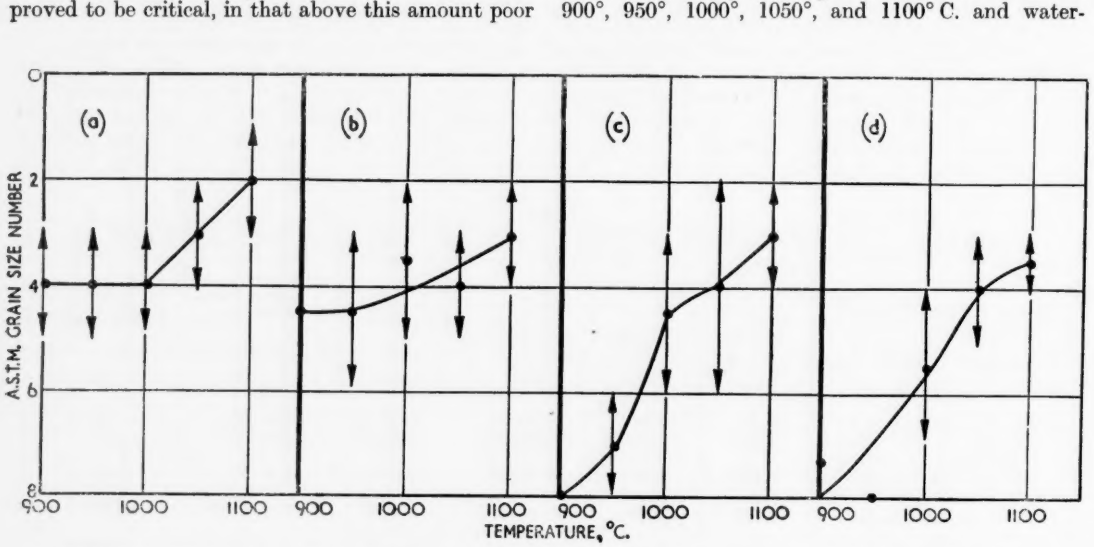
* Heat-treatment temperature based on that to produce A.S.T.M. grain size 4

condition of heat-treatment (920° C., A.C.). These steels were selected as being representative of coarse-grained (21), mixed-grained (30 and 52), and fine-grained steels (47 and 57). Two samples of steel 30 were examined: one contained 0·011% of soluble aluminium, the other 0·018%, giving good and poor creep properties, respectively. No nitride was found in the coarse-grained steel (21) and a relatively small amount (0·0017% Al as AlN) in the sample of steel 30 containing 0·011% of soluble aluminium, both of which showed good creep resistance. The remaining four specimens (steels 47, 52, 57, and 30 containing 0·018% of soluble aluminium) had between 0·0042% and 0·0064% of aluminium present as AlN and were of poor creep resistance.

These results show that whilst both soluble aluminium content and McQuaid–Ehn grain size give a measure of the creep resistance of steels normalized at one specific temperature, both criteria are possibly in effect a reflection of the tendency for a given steel to form aluminium nitride.

The fact that 0·015% of soluble aluminium has proved to be critical, in that above this amount poor creep strength is encountered, can perhaps be explained on the basis that this amount of aluminium is necessary in the steel to ensure the presence of sufficient aluminium nitride to cause appreciable reduction in the creep properties at any one normalizing temperature (*e.g.*, 920° C.). This particular value (0·015%) of soluble aluminium has been cited[10] as a lower limit for the production of elongated grains in aluminium-killed sheet steel of similar composition to those considered in this paper, and it seems likely that a similar mechanism is involved in the prevention of strain ageing and in favouring graphitization, all of which processes appear to be connected with the presence of AlN.

It would therefore appear that the creep resistance of any of the steels correlates directly with the aluminium nitride content, which in turn is related to the soluble aluminium content and grain-size characteristics. This is illustrated in Fig. 3 for four steels (20, 25, 44, and 46), representative of two coarse- and two mixed-grain steels. These results were obtained by soaking small discs for 1 hr. at 900°, 950°, 1000°, 1050°, and 1100° C. and water-



(*a*) Steel 20: 0·003% soluble Al (*b*) Steel 25: 0·004% soluble Al (*c*) Steel 44: 0·029% soluble Al (*d*) Steel 46: 0·034% soluble Al

Fig. 3—Grain-coarsening characteristics

quenching. A creep test was then made on each steel normalized from the appropriate temperature to give the equivalent of A.S.T.M. grain size 4 in each instance. The results of these tests and those made on specimens in the 920° C., A.C., condition are given in Table VI. On the basis of previous results (Table V), steels 20 and 25 would not be expected to contain any aluminium nitride. Steels 44 and 46 would, however, contain nitride at about 900° C., this nitride going into solution at the higher austenitizing temperatures. Such behaviour is substantiated by the respective grain-coarsening characteristics and by the creep resistance, where the wide variation shown by these steels upon normalizing from 920° C. has been largely removed upon normalizing from higher temperatures, when little, if any, AlN would be out of solution and the grain sizes were substantially similar.

Owing to the fact that the samples constituting the major part of the investigation were not available for examination by aluminium nitride analysis, it has not been possible to provide as comprehensive a picture as might, in retrospect, have been desirable.

CONCLUSIONS

The results of a detailed examination of the creep strength of B.O.H. mild steel killed with amounts of aluminium ranging between 1 and 2½ lb./ton have served to show the importance of the (residual) soluble aluminium content of the solid steel in controlling this. It has been shown that, using the B.S.1271 test as criterion, normalized steels containing 0·015% or less of soluble aluminium give good creep properties, whilst those with more than this amount give poor creep resistance. From a practical point of view it would appear that steels of good creep resistance can be obtained with aluminium additions of up to 1½ lb./ton, provided that mould additions of aluminium are limited. It has not been found possible to relate the amount of residual aluminium in the solid steel to the deoxidation conditions, owing partly to the effect of atmospheric oxidation and partly to the reaction with slag, both of which exert considerable influence on aluminium recovery.

The residual oxygen content of these steels bears no relationship to the creep strength, but the McQuaid–Ehn grain size shows a relation, inasmuch as steels having a grain size of 4 or less will always possess adequate creep properties. This should be a useful basis of differentiation, although it should be emphasized that steels are not necessarily deficient in creep strength if the McQuaid–Ehn grain size is finer than 4.

An attempt has been made to investigate the function of aluminium in these steels. This has led to the view that, whilst a soluble aluminium content of about 0·015% and above results in fine or mixed grain size with generally poor creep strength in steels normalized from 920° C., the controlling factor is aluminium nitride, by virtue of its influence upon the grain size.

Acknowledgments

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Reducibility of Iron-Ore Lumps

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SYNOPSIS

The physical structure, controlled by the pore system, of a hematite ore in the ignited state was studied. This comprised (*a*) measurement of the total porosity by the powder method, (*b*) determination of the permeability to gases by measurements of air flow through discs of ore, and (*c*) computation of the average pore size from air-flow measurements using the viscous slip phenomenon, a method which might be applied to other porous materials.

The relative chemical reducibility was determined from reduction/time curves of ore spheres in a stream of H_2 at 800°C. The extent to which the physical factors affect the chemical reducibility was investigated and the effect of the diameter of the sphere was assessed. 981

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Introduction

It has been shown by many investigators that ore reducibility is among the principal factors controlling the respective amounts of direct and indirect reduction in the blast-furnace and thus the fuel economy. The question of reducibility has also

been raised in formulating quality standards for agglomerates.

The early experiments by Wüst and Rütten[1] showed the importance of the physical structure of the ore in determining its reducibility. Subsequently certain physical properties have been used as a means of correlating relative rates of reduction for different ores. For example, Diepschlag, Zillgen, and Poetter[2] found that the reducibility is directly proportional to the total pore surface (in sq. cm./c.c. of ore), *i.e.*, (total porosity)/(pore dimension). They determined the total pore surface by using a microscopical point-counting technique on polished sections.

Joseph[3] found that the reducibility is directly proportional to the total porosity as determined by the powder method. He further recognized the possibility of variations in the character of the porosity and says "permeability measurements showing the effect of difference in the character of the porosity probably would show a closer relation to reduction rates than total porosity values, which do not indicate whether the pores are large or small or interconnected."

Pokhvisnev and Goncharevskii[4] concluded from their work that the pore surfaces and not the porosity should serve as an indication of reducibility. They determined the surface of pores by an adsorption technique, in which only the pores with access to the lump surface are taken into account. Again, this is the same as (porosity accessible from the surface)/(average pore dimension).

Saunders and Tress[5] found that the reducibility of the ore by blast-furnace gas is directly proportional to the porosity relative to air and mercury as determined by the 'S.K.' (South Kensington) method. This method necessarily implies the participation of pores which are accessible from the surface, but will not include those which are completely sealed.

Some workers [6–8] failed to establish on a variety of ores the direct relationships found by Joseph or Saunders and Tress. They pointed out, however, that certain picked samples exhibited these direct relations, although in every case the general effect that the more porous ores are also the more reducible was found. The only apparent contradiction to this general rule was some results reported by Philbrook[9] and explained as "possibly due to an apparently greater tendency of the *A* ore (lower porosity) to crack during preliminary dehydration and during reduction." This observation thus brings his results into agreement with the general rule.

Evidently, therefore, there is some uncertainty about the quantities controlled by the pore-system characteristics which can serve as an index of reducibility. The following four, generally different, physical quantities are used:

(i) Total porosity
(ii) Porosity accessible to the surface ('permeable porosity')
(iii) Total porosity divided by the average pore dimension
(iv) Permeable porosity divided by the average pore dimension.

If the permeable porosity and the total porosity could serve as a quantitive index of each other, then (i) and (ii) would be equivalent, but generally this is not the case, as emphasized by Joseph, Barrett, and Wood[10] and shown by El-Mehairy.[11]

Although this uncertainty might be attributed to differences in the characters of different ores, a systematic study of the influence of the pore-system characteristics on the chemical reducibility of the ore would be desirable, and is treated in the present investigation.

Besides the internal physical structure, the external characteristics of size and shape of a lump of ore must be considered. It is logical to expect that reducibility is a function of lump size; laboratory investigations, however, have failed to establish a clear-cut relationship. Wetherill and Furnas[12] discerned no effect up to a diameter of 1 cm. Udy and Lorig[13] found that for three small single magnetite particles the percentage loss of oxygen after a certain reduction time increases as the diameter decreases. Specht and Zapffe[14] expressed a relationship between screen mesh diameter and time for complete reduction of small particles of magnetite by hydrogen at 600° C., but pointed out that the significance of the average diameter of such irregular particles might be argued.

For larger sizes Stålhane and Malmberg,[15] working with a magnetite ore, showed that the time for complete reduction is about proportional to the diameter in the range 1–4 cm. Kamura,[16] working with a hematite ore, showed that the time for almost complete reduction was doubled when the particle weight was increased about four times. The particles were irregular in shape and he estimated that the linear dimension was increased from 1 to 2 cm. Diepschlag, Zillgen, and Poetter[2] showed that for a certain reduction treatment the degree of reduction decreases hyperbolically as the diameter of the nearly spherical specimen increases (the degree of reduction is nearly inversely proportional to the diameter) and that the relation is the same for all ores tested. Recent work

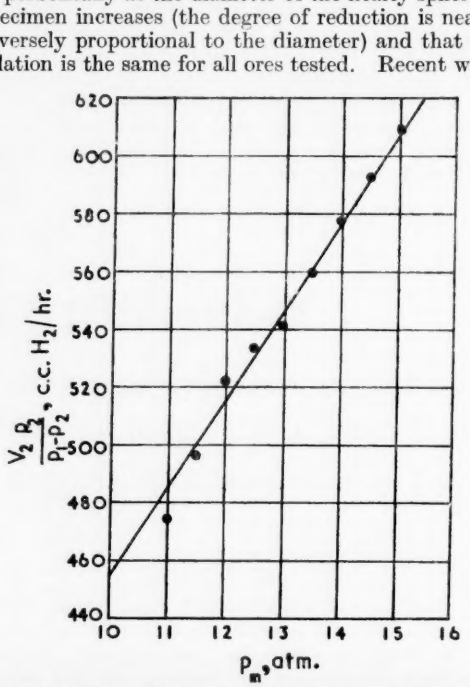
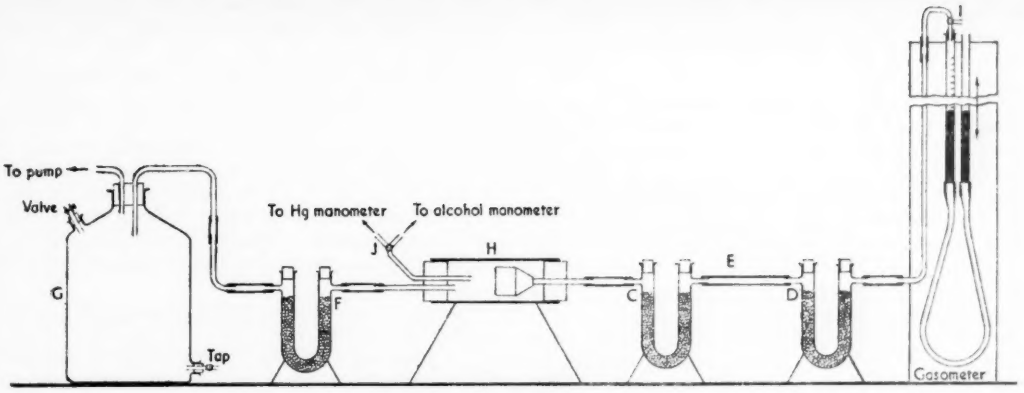


Fig. 1—Flow of hydrogen through an ore plug



C, D, F — Anhydrone drying tubes.
G — Aspirator bottle.
H — Fused-silica tube.
I, J — 3-way stopcocks.

Fig. 2—Apparatus for measuring rate of dry-air flow through iron-ore plugs

by Lewis[17] indicated that the time required for 90% reduction is directly proportional to the volume of the cubes of ore used. Melcher and Cajado,[8] working with Brazilian ores, showed that the rate of reduction is inversely proportional to the volume of ore cubes between 3·3 and 15·6 c.c. and diminishes rapidly for larger volumes.

Raw Materials

The hematite deposits in the Asswan district, Upper Egypt, were chosen as raw materials for the present work. These sedimentary deposits are of an oolitic nature and are found in the Nubian Sandstone of the Upper Cretaceous. Fifteen fairly big lumps (indicated by I–XV) were selected from the different fields and seams, covering as wide a range of properties as possible. Since the lumps are probably not representative their exact locations are not given.

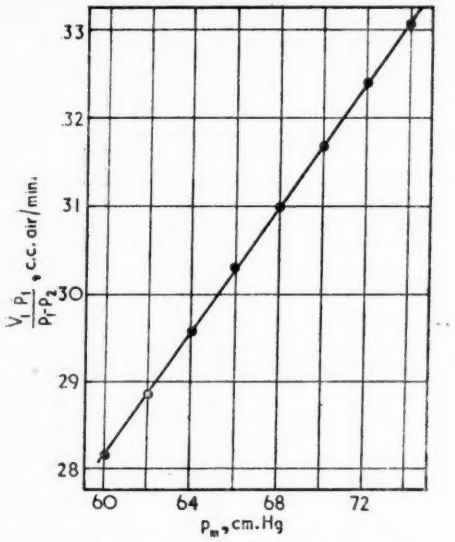


Fig. 3—Flow of dry air through an ore plug

The iron is present in the ferric state and an example of the chemical composition is:

Lump I

Loss on ignition, % 1·46

Fe_2O_3, %	FeO, %	SiO_2, %	Al_2O_3, %	CaO, %
80·12	trace	8·01	2·60	3·99
MgO, %	MnO, %	TiO_2, %	P_2O_5, %	S, %
0·86	0·16	0·01	2·62	0·03

PORE-SYSTEM CHARACTERISTICS

A natural pore system is a complex one, but its characteristics may be simplified as follows, assuming uniform distribution of pores through the groundmass:

(i) Geometry of the pore
(ii) Dimensions of the pore
(iii) Total number of pores per unit volume of the ore
(iv) The number of permeable pores per unit volume of the ore, for a certain lump, *i.e.*, the extent of interconnection between the pores.

If the pore shape is assumed to be constant for the different lumps from the same geographical locality and of the same geological formation, an assumption partially substantiated by Morton,[6] the pore system can be characterized by (*a*) total porosity, (*b*) pore size, and (*c*) gas-permeability.

Porosity

This was determined for the pre-ignited specimens (heated gradually in an air stream to 900° C. and ignited to constant weight at this temperature) by the powder method:

$$\text{Porosity, \%} = \left(1 - \frac{\text{apparent specific gravity}}{\text{true specific gravity}}\right) \times 100.$$

The true specific gravity was determined on −200 mesh (B.S.S.) powder using the specific-gravity bottle method with absolute alcohol as the pyknometer fluid. The apparent specific gravity was obtained by dividing the weight of the lump (cylinder) by its volume. The volume was measured by a method similar to that used by Lewis.[17]

Average Pore Size and Relative Gas-Permeability

Flow of Gas through Porous Media—The flow of gas

through a porous plug can be generally described[18] by:

$$V_1=\frac{n\,\pi\,a^4}{8\,\eta\,L}\cdot\frac{p_1^2-p_2^2}{2\,p_1}\left(1+\frac{4\epsilon_m}{a}\right) \quad \ldots\ldots\ldots\ldots(1)$$

where V_1 is the rate of gas flow measured at p_1; p_1, p_2 are pressures at inlet and exit faces, respectively; η is the viscosity of the gas; ε_m is the coefficient of slip at a mean pressure $p_m = \frac{1}{2}(p_1 + p_2)$; a is the fictitious pore radius; n is a number depending upon the extent of interconnection between the pores; and L represents a length of path for flow from one face of the plug to the other. The quantities a, n, and L depend upon the nature and geometry of the porous plate and are constants for the same plug.

Computation of a—Since at a constant temperature $\varepsilon_m p_m = \varepsilon_0 p_0$ (p_0 = standard pressure), equation (1) can be rearranged as follows:

$$\frac{8\,\eta\,L}{n\,\pi\,a^4}\cdot\left(\frac{V_1 p_1}{p_1-p_2}\right)=p_m+\frac{4\varepsilon_0\,p_0}{a} \quad \ldots\ldots\ldots\ldots(2)$$

If $V_1p_1/(p_1-p_2) = 0$ it follows that $a = -4\varepsilon_0 p_0/p_m$. Thus a can be computed from the intersection of the linear relation $V_1p_1/(p_1-p_2)$ *vs.* p_m with $V_1p_1/(p_1-p_2) = 0$.

However, if only two gas-flow measurements at two different pressure differences (indicated by subscripts 1 and 2) are available, a can be computed from the following derivation from equation (1):

$$\frac{(V_1)_1}{(V_1)_2}\cdot\frac{(p_1)_1}{(p_1)_2}\cdot\frac{(p_1-p_2)_2}{(p_1-p_2)_1}=\frac{a(p_m)_1+4\epsilon_0 p_0}{a(p_m)_2+4\epsilon_0 p_0} \quad \ldots\ldots(3)$$

Computation of a *from Previous Data on Iron Ores*—Following Carson's determination[19] of the pore size in paper by using the slip phenomena at atmospheric pressure, equation (2) was applied to determine the average pore radius from available data on gas flow through an iron-ore plug. Wüst and Rütten[1] measured the flow of gas through a 'raw' prismatic specimen cut from an iron ore (Minette 9) and Fig. 1 shows these data plotted as $V_2p_2/(p_1-p_2)$ *vs.* p_m. If extrapolated the straight line will intersect $V_2p_2/(p_1-p_2) = 0$ at $p_m = -0{\cdot}46$. Taking ε_0 for H_2 at 17° C. and 760 mm. Hg as $11{\cdot}8 \times 10^{-6}$ cm., $a = 1{\cdot}03 \times 10^{-4}$ cm.

Apparatus—The principle of the apparatus is to measure the time required for drawing, under a certain pressure difference across a disc of ore (the mean pressure being a reduced one), a certain volume of dry air at atmospheric pressure and room temperature. The main parts of the apparatus (Fig. 2) are: (*a*) a mercury gasometer with levelling tube, to keep the pressure inside atmospheric; (*b*) a specimen holder, to which the ore plug is cemented with beeswax; (*c*) a suction pump to create a difference of pressure across the specimen. The apparatus was checked for leaks by using a brass solid disc in place of the porous plug.

Specimens—As the ore under investigation does not exhibit directional properties for the flow of gas,[11] it was unnecessary to experiment with both directions. All the discs or short cylinders of ore were cut with faces parallel to strata. The specimens were heated gradually in an air stream to 900° C., ignited to constant weight at this temperature, and the loss on ignition checked.

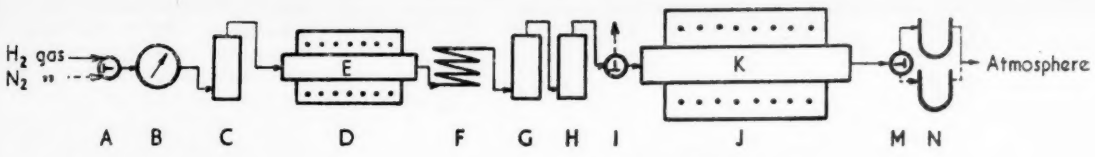
Since the accuracy of the pore-size computation depends upon the accuracy with which the volumetric rate of gas flow is measured and the extent to which steady conditions are maintained, the dimensions of the ore specimens were adjusted accordingly for the apparatus being used. Any apparatus measuring gas flow accurately could be used and the technique would be applicable for other gases, at reduced as well as high mean pressures, according to the nature of the porous plug under investigation.

The discs used for permeability measurements were all of the same dimensions, *i.e.*, 25 mm. dia. and 4 mm. thickness. The thickness was kept constant as its effect on L/n is unknown. A pressure difference of 32 cm. Hg was used as a standard; to maintain the same accuracy of gas-flow measurements, lower pressure differences were used when necessary and values of volumetric rate of air flow were recalculated to the 32-cm. Hg standard using equation (3) with a as computed from a twin short cylinder. No attempt was made to calculate the permeability on an absolute basis, as the investigation is a comparative one.

Table I

EFFECT OF PORE-SYSTEM CHARACTERISTICS ON REDUCIBILITY OF IRON-ORE LUMPS

Sphere No.	Lump No.	Porosity, %	Total Water Collected, g.	Time for 90% Reduction, min.	Relative Reducibility	Relative Permeability
1	I	42·0	5·34	64·5	15·5	18·5
2	II	37·3	4·36	72·0	13·9	17·4
3	III	43·5	5·54	62·0	16·1	31·3
4	IV	39·4	4·03	67·5	14·8	84·3
5	V	47·3	4·72	58·0	17·2	159·7
6	VI	37·1	6·03	71·5	14·0	31·6
7	VII	42·3	5·60	64·5	15·5	19·1
8	VIII	46·1	5·25	59·5	16·8	32·9
9	IX	47·4	5·61	57·5	17·4	24·2
10	X	40·8	6·14	65·5	15·3	61·4
11	XI	31·9	5·10	81·5	12·3	27·7
12	XII	45·3	5·10	60·0	16·7	50·4
13	XIII	48·5	4·93	56·5	17·7	113·2
14	XIV	39·9	5·35	67·5	14·8	32·1
15	XV	42·3	4·32	64·0	15·6	31·6



A, I, M — 3-way stopcocks.
B — Flow meter.
C, G — $CaCl_2$ drying towers.
D, J — D.C. tube furnaces.
E — Pyrex tube filled with fine pure copper turnings at about 600° C.
F — Pyrex cooling coil.
H — Anhydrous magnesium perchlorate drying tower.
K — Reduction tube.
L — Pyrex leading tube.
N — Absorption U-tube.

Fig. 4—Reduction apparatus

Example of Pore-Size Computation—The data obtained from air-flow measurements through specimen 44 (25 mm. dia. and about 24 mm. thickness) are plotted in Fig. 3 as $V_1p_1/(p_1-p_2)$ *vs.* p_m. If extrapolated the line intersects $V_1p_1/(p_1-p_2)=0$ at $p_m=-19{\cdot}8$. Taking ε_0 for air at 17° C. and 760 mm. Hg as $6{\cdot}4\times10^{-6}$ cm., $a=0{\cdot}98\times10^{-4}$ cm. $\simeq 1\ \mu$.

For the same specimen the following two sets of measurements were obtained:

$(p_1-p_2)_1=34{\cdot}2$ cm. alcohol $\equiv 2$ cm. Hg $\quad (p_1-p_2)_2=32$ cm. Hg
$(Q_1)_1=5$ c.c. $\quad (Q_1)_2=24$ c.c.
$(t)_1=341{\cdot}5$ sec. $\quad (t)_2=121{\cdot}5$ sec.

where Q_1 is the volume of dry air, at pressure p_1, streaming through the specimen in time t.

Equation (3) then gives $a=0{\cdot}95\times10^{-4}$ cm. $\simeq 1\ \mu$, the same value as that calculated from Fig. 3.

Results

The average pore radius a was found to be $1{\cdot}0\times10^{-4}$ cm. for all fifteen lumps tested.

Table I summarizes the values obtained for the relative permeability; these are actually volumetric rates of air flow (c.c./min.) through standard-sized discs of ore (25 mm. dia. and 4 mm. thickness) at a pressure difference of 32 cm. Hg, and measured at atmospheric pressure and room temperature. Although these are not strictly permeability values, they are a measure of this quantity for all standard-sized specimens tested under identical conditions, and will be referred to subsequently simply as permeability.

The porosity values obtained for the specimens used are very nearly the same ($\pm 1{\cdot}2\%$) as those given in Table I.

CHEMICAL REDUCIBILITY

As the present investigation is a comparative one, hydrogen gas was used as the reducing agent. The index used by Wüst and Rütten[1] and established by Joseph[3] is adopted to express reducibility. It is the reciprocal of the time required for 90% reduction to be accomplished.

Since the ore could be satisfactorily prepared as spheres,[11] this shape was adopted throughout; a standard diameter of 25 mm. was chosen, except when studying the effect of diameter on reduction. A diagram of the apparatus is given in Fig. 4.

Experimental Details

Position of Sphere—The ore sphere was kept in the centre of the constant-temperature hot zone of the reduction tube, in an approximately coaxial position, by using thick-gauge Nichrome wire spirals perpendicular to each other.

Flow of Gas—A constant rate of 4 l./min., measured at room temperature, was used throughout the work. Such a high rate minimizes the effect of linear gas flow, referred to later, prevents condensation of water vapour on its way from the reduction tube to the absorption tubes, provides an ample excess of reducing gas in the reduction tube at all times for the different sizes of spheres used, and sweeps the water from the furnace almost as rapidly as it is formed.

Pressure—The pressure in the reduction tube was that just necessary to overcome the resistance to gas flow.

Temperature—A temperature of 800° C. was selected[1,3,17,20] for the reduction and was measured by a thermocouple inserted in the reduction tube next to the specimen. The temperature limits were ± 3° C.

Reduction Furnaces and Tubes—Two D.C. tube furnaces were used together with suitable reduction fused-silica tubes. The first 1·8-kW. furnace J_1 contained a silica tube K_1 ($1\frac{7}{16}$ in. internal dia.), and the second 2·4-kW. furnace J_2 a silica tube K_2 ($2\frac{1}{4}$ in. internal dia.). The first assembly was used for spheres of 25 mm. dia. and less, and the second for bigger sizes (30–42 mm.). The silica tubes were well insulated at the furnace-tube ends to provide high thermal head.

Absorption Tubes—The absorption U-tubes were of large size and were filled in a way similar to Lewis's.[17] The air in them was replaced by dry hydrogen using stopcock *I*.

Linear Rate of Gas Flow—With a constant rate of gas flow the velocity of the hydrogen over the ore sphere varies according to the area of free space around the sphere. A number of investigators[12, 13, 21–24] showed effects on the reduction rate due to variations in the gas velocity. Some of them[12, 13] showed that for some ores a certain saturation velocity exists, *i.e.*, a velocity beyond which there is no effect on the reduction rate. Wild and Saunders's report,[25] that the degree of surface reduction and the oxygen gradient within the lump do not seem to be linked in any way with changes in the linear rate of gas flow, indicates that the limits used in their investigation were above the saturation velocity. Woods[26] pointed out the importance of carrying out reduction experiments under conditions of calculable (or better negligible) dynamic similarity, if sound comparison of ore properties is desired. In this work a negligible dynamic similarity exists in all experiments carried out on the standard-sized spheres, although there is no simple distribution of linear velocity at different parts of the periphery.

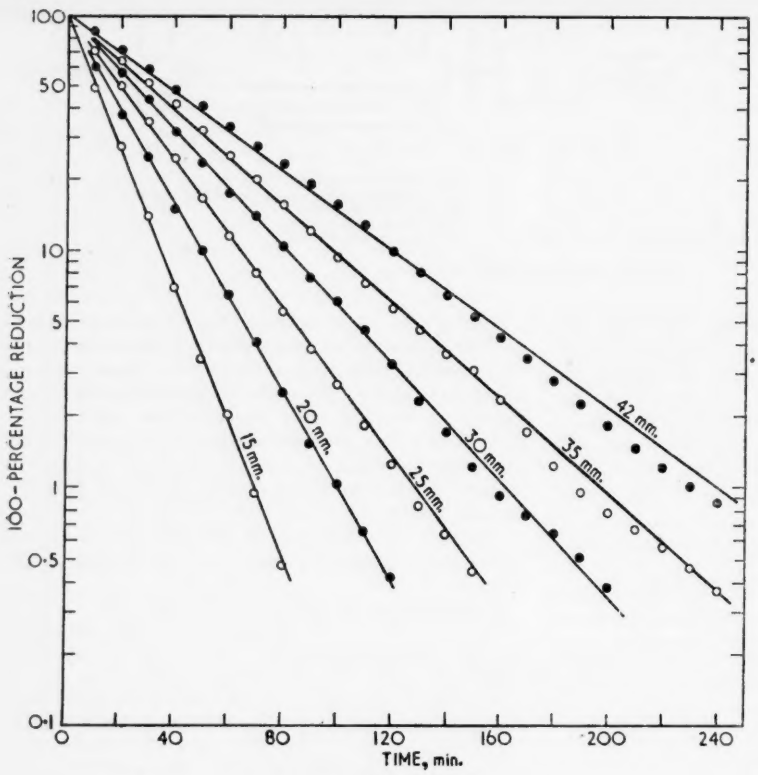


Fig. 5—Reduction curves

When assessing the effect of sphere diameter it was necessary to ensure that any effect due to variations in gas velocity was kept at a minimum. Twin spheres of the standard size, from the same lump used for investigating the effect of size (No. I), were tested under identical conditions, except that one experiment was carried out in K_1J_1 reduction tube and furnace and the other in K_2J_2. The two experiments gave similar reducibility results.

In the K_1 tube the maximum free space round the sphere, neglecting the cage, is 10·45 sq. cm. and the minimum 5·55 sq. cm., whereas in K_2 tube the corresponding values are 25·5 sq. cm. and 20·6 sq. cm. As a basis for comparison an arbitrarily chosen arithmetic mean is used, *i.e.*, 8 sq. cm. for K_1 and 23 sq. cm. for K_2. Thus a ratio of linear flow of the order 3:1, within the limits used, does not seem to have any appreciable influence on the reducibility. However, for spheres of diameter greater than 25 mm. (those of 30 and 35 mm. dia. used in the K_2 tube) packings of concave silica pieces from broken tubes were used to reduce the free area round the sphere perpendicular to flow by about 4 sq. cm. For the 15-mm. spheres, the smallest size used, two identical specimens were placed in such a position as to decrease the free area round them; this arrangement in addition furnished more water vapour for weighing. Table II gives the arithmetic mean of the maximum and minimum free areas, neglecting the cage, for the different spheres used. The probable limits of velocity at 800° C. for mean free areas of 8 and 18·6 sq. cm. are about 31 and 13 cm./sec., respectively.

Porosity of Spheres—The porosity of each sphere in the ignited form was determined by the powder method. As the starting shape for making the spheres was cylindrical, the extra pieces taken off the cylinders were used for individual true specific-gravity determinations, to ensure accurate values for this quantity.

Experiments were confined to spheres which gave values of the quantities found in the porosity determinations to within narrow limits. All specimens were gradually heated, in an air stream, to 900° C. and ignited to constant weight at this temperature.

Experimental Procedure—This is familiar and provides data for constructing a percentage-reduction/time curve, from which the reducibility is determined.

The reduction was considered substantially complete when the **U**-tube gained less than 5 mg. (equal to about the weight of the blank) in 10 min. The weight of the specimen after reduction furnished a check on the total amount of water collected. The blank, which was 3–4 mg. of water per 10-min. interval, was neglected as neglibible compared with the total of about 5 g. of water obtained.

Results and Discussion

Reduction Curves and Reducibility Index—It is clear from Fig. 5 that the reduction follows an exponential curve, nearly of the first order, especially with the smaller sizes and in the early stages, *i.e.*, up to 90% reduction. This gives weight to the use of the reciprocal of the time required for 90% reduction as describing quantitatively the behaviour of reduction.

Table II

ARITHMETIC MEANS OF FREE AREAS

Diameter of Sphere, mm.	Reduction Tube	Maximum Free Area, sq. cm.	Minimum Free Area, sq. cm.	Arithmetic Mean, sq. cm.
15*	K_1	10·5	6·9	8·7
20	K_1	10·5	7·3	8·9
25	K_1	10·5	5·5	8
30†	K_2	21·5	14·4	18
35†	K_2	21·5	11·9	16·7
42	K_2	21·5	11·7	18·6

* Two spheres used. † Packing used.

As seen from Fig. 5, this reciprocal is an index to the slope of the almost linear relations of the semi-logarithmic plots. The equation would be of the form $w/W = 1 - e^{-Kt}$, where W = amount of oxygen available for reduction, w=amount of oxygen removed after time t from the start of reduction; K will be the required index of reducibility.

It can be shown that this index is proportional to Philbrook's slope index[9] and to that used by Elliot and coworkers,[27] and that the more the reduction curve deviates from the first order, the more these indices lose proportionality.

Effect of Particle Diameter on Reducibility—Figure 6 is plotted for spheres cut from the same lump (No. I) with porosities of 41·6–42·4%. It shows that $t_{90} \propto D^{1.18}$, or approximately $t_{90} \propto D$. This result appears to contradict the results reported by Lewis,[17] and Melcher and Cajado.[8] However, the rate of hydrogen flow in the present work is five times as much as that used by them and, as also observed by Woods,[26] the amount of available oxygen in the bigger cubes of Lewis was much more than that in the bigger spheres of the present investigation.

With this high rate of flow the power of the diameter was 1·18 and this will probably approach unity as the flow is further increased to a value comparable with actual practice. This is confirmed by Joseph[3]: "The size of the ore should vary inversely with the time required for reduction, that is, ore requiring twice as long as the 'Utah' ore for 90% reduction should be crushed to half the size."

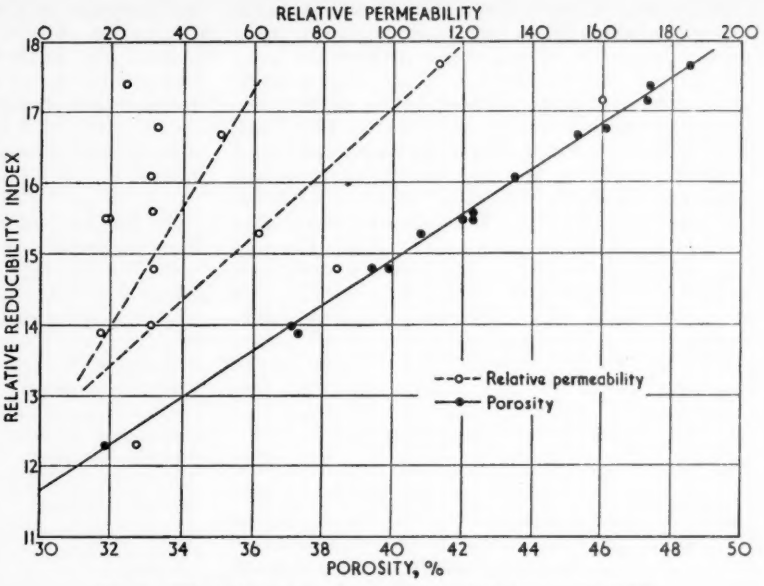


Fig. 7—Effect of pore-system characteristics on reducibility

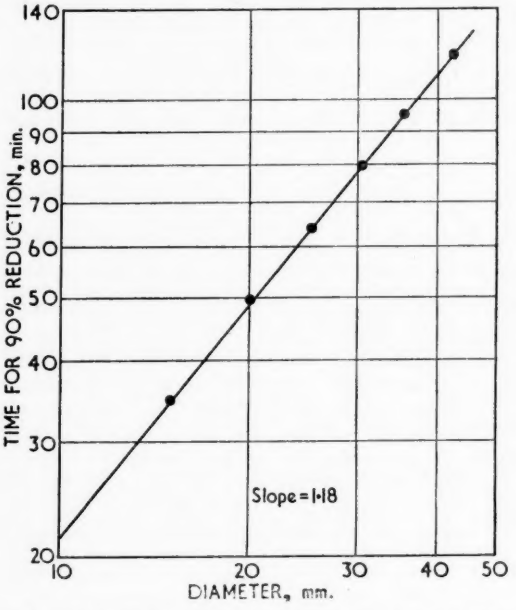


Fig. 6—Effect of particle diameter on time for 90% reduction

In the advance of solid phases in partially reduced spheres, El-Mehairy has shown[28] that the advance of metallization, which is the slowest and thus the controlling stage in reduction, is linear and independent of sphere size. This is a further confirmation of the direct proportionality between diameter and reducibility.

EFFECT OF PORE-SYSTEM CHARACTERISTICS ON REDUCIBILITY

Table I summarizes relative permeability, porosity, and reducibility data for the standard-sized spheres cut from different lumps. It has been shown[11] for this ore that the permeability after ignition is predominantly influenced by the percentage loss on ignition. As the loss on ignition and porosity of the spheres tested for reducibility are very nearly the same as those tested for permeability and pore size, it is considered justifiable to adopt the same value for the relative permeability and an average pore diameter of 2×10^{-4} cm. for all spheres.

Figure 7 shows that the reducibility is directly proportional to the porosity, provided that the pore size is the same. The straight line extrapolated cuts the reducibility axis at 2, when the porosity is zero; thus this non-porous sphere would require about 500 min. to attain 90% reduction as compared with 71·5 min. for the 37% porous one. Such a positive value for reducibility when the porosity equals zero is to be expected, for a non-porous lump should show a certain amount of reduction.

The diagram shows as well that no correlation exists between reducibility and permeability, or reducibility and the extent of interconnection between the pores (as the pore size is the same), although possible correlations have been indicated by the dotted lines. This is the first experimental evidence that the reducibility of iron-ore lumps is not appreciably influenced by the permeability, provided that the pore size and shape are the same. Barrett[29] came to a similar conclusion, working on the burning-out (oxidation) of combustibles from refractory clay cubes. The rate of recession of the unoxidized core increased with increasing porosity but permeability was also a factor at very low porosities. Later work on cubes of controlled pore size removed the anomaly of the permeability factor. The presence of definite reduction phase-boundaries in the partially reduced ore-lumps[28, 30] may be said to support the conclusion that reducibility is independent of permeability.

Available Oxygen

Table I indicates that the reducibility is not appreciably influenced by the total amount of water formed from the complete reduction of the standard-sized spheres. As all the spheres were of the same volume, the total water formed is a measure of the amount of available oxygen (or Fe_2O_3) per unit volume of ore-lump.

Dickie[7] found that the times for 90% reduction in both carbon monoxide and hydrogen are directly proportional to the weight of iron present in the standard-sized cubes, magnetite being the only ore tested which failed to conform to this rule. As the relevant data have not been published, their bearing on the present work cannot be assessed. Several authors suggest that reduction is a diffusion-controlled process; thus the presence of more water vapour diffusing outwards from the seat of the reaction is regarded as counterbalanced by the increased ease of diffusion through the more open structure of the outer layers caused by the removal of oxygen atoms from the lattice, although this process has not been studied quantitatively.

CONCLUSIONS

(1) The rate of reduction, with H_2 at 800° C., follows approximately a first-order exponential law.

(2) The reducibility is inversely proportional to the diameter of the ore lump (sphere).

(3) The reducibility is directly proportional to the total porosity of the ore, provided that the average pore size is the same.

(4) The extent of interconnection between the pores and hence the permeability to gases (since the pore size is the same) has no appreciable influence on the reducibility.

(5) Provided that the porosity and average pore size are constant, reducibility is unaffected by the relative values of Fe, differing Fe:O ratios in specimens having essentially the same size and shape.

Acknowledgments

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An Improved Model for the Calculation of Heat Transfer in the O.H. Furnace

By M. W. Thring, M.A., F.Inst.F., F.Inst.P., and D. Smith, B.Sc., Ph.D.

SYNOPSIS

The model used to calculate average roof temperature and thermal efficiency during the melting period and the melting time in an O.H. furnace at various fuel input rates gave higher efficiencies (22–55%) than those obtained in practice (15–25%), except for an unusually bad flame, which had slow combustion combined with very low emissivity. The attempt to improve the model by allowing for a thermal resistance in the slag equivalent to that of 4 in. of solid steel gave an appropriate drop in efficiency, but this immediately implied that the fuel rate would have to be cut much more than in fact it is to avoid overheating the roof. The slag thermal resistance cannot therefore be equivalent to more than 1 in. of steel, presumably because of the violent stirring.

An improved model in which the flame was taken as spreading to only half the width of the bath at the outgoing end gave very close agreement with the observed melting time and thermal efficiency, and when thermal resistance equivalent to that of 1 in. of steel was incorporated it gave accurate agreement also with the observed maximum fuel input rate for a given maximum roof temperature. It can be concluded that in an actual furnace where the roof is not at the maximum temperature for the greater part of the melting time, increasing the bath coverage by the flame is a method of reducing the fuel consumption and the melting time comparable to raising the flame emissivity.

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STATEMENT OF THE PROBLEM

PREVIOUS papers[1–3] have presented models for calculating the heat transfer from the flame to the charge during the melting process in the O.H. furnace. These models have been useful in that they have enabled the effect of flame length and emissivity on the roof temperature, melting time, and fuel consumption to be calculated. They have, however, shown thermal efficiencies much higher than those obtained in practice. In the present paper, therefore, the effect of making various alterations to the model which are consistent with present knowledge of combustion and heat transfer will be explored. By comparing the melting time, maximum roof temperature, and rate of fuel input with those actually obtained on a typical 100-ton furnace, the actual values of the parameters in the model can be determined. This in turn enables very practical conclusions to be drawn on the ways in which the heat-transfer rate and fuel consumption can be greatly improved.

ALTERATIONS TO THE MODEL

Resistance of the Slag to Heat Transfer

The simple model given in a previous paper[2] (called here Model 1) assumed that all the heat necessary to melt the steel entered the steel directly by radiation from the flame and roof, the steel surface and the whole of the steel being at a temperature of 1500° C. throughout. Model 1 gave thermal efficiencies during the melting period of 22·5–55%, the former corresponding to a very high fuel input rate (4000 lb. of oil per hr.) with a flame which is certainly worse than any occurring in practice, *viz.*, having delayed combustion combined with a low emissivity (flame 3). In effect the flame emissivity will never fall as low as 0·1, but will remain at about 0·2–0·3. For more realistic flame properties, therefore, the model gave efficiencies considerably higher than those found in the actual furnace during the melting period.

The first suggestion to bring the model into line with actual furnaces would clearly be, therefore, to allow for the thermal resistance of the liquid slag between the flame and the cold metal as was done in some other calculations.[4] In another paper by the author[3] this allowance was made by the simplest device of supposing that the slag surface temperature was 1600° C. when the steel was at 1500° C. This gave an increase immediately of 88° C. in the maximum roof temperature, but only reduced the thermal efficiency from 44% to 38% in the case of the 2000-lb./hr. short flame calculated. It was clear that the introduction of a thermal resistance would give a better account of the effect, since the temperature gradient across the slag is then greater at points where the heat-transfer rate is greater. A thermal resistance equivalent to that of 4 in. of cold steel was therefore tried, because this was the value used previously by the author,[4] and because the thermal resistance of 4 in. of slag would clearly be greatly reduced when the slag was stirred and fully liquid. The results for this case (Model 2) are shown in Table I*b* and indicate that such a thermal resistance makes a small change in the efficiency, but raises the maximum roof temperature to an impossibly high value even at a fuel input rate of 2000 lb./hr.

The conclusion is, therefore, that either (i) the charge in the O.H. melts under conditions where the thermal resistance between the slag surface and the metal is considerably less than that corresponding to 4 in. of solid steel, or (ii) the greater part of the heat for melting is supplied while the surface of the slag is considerably below 1500° C. Hence this alteration to the model cannot bring the required agreement.

Heat Losses through the Roof

The heat losses through the roof were assumed to be 2000 C.H.U./sq.ft. hr. in Model 1, this value being already twice that which one would expect from laboratory measurements of the thermal conductivity of the bricks. At first sight it might be expected that

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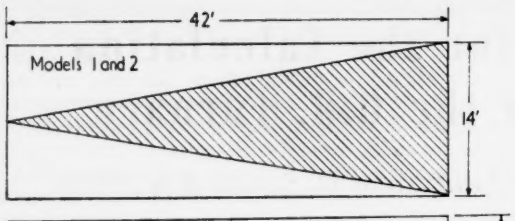

Fig. 1—Diagrammatic representation of position occupied by the flame on the bath used in O.H. model calculations

a further increase in it would suffice to bring the calculated model into line with an actual furnace. This is not possible, however, because an increase in the roof heat loss can lower the thermal efficiency, but when the fuel input rate is increased to give melting times corresponding to those obtained in practice, the roof temperatures rise very high. Now a doubling of the roof heat loss only suffices to lower the roof temperature by a few degrees because, as has been pointed out previously,[1] the gross radiation to the roof is about 20–100 times the net heat flow to the roof, and thus the inside temperature of the roof is almost entirely decided by the level of the gross radiation.

Flame Shape

Alterations to the flame shape assumed in the model might be expected to be to a certain extent equivalent to alterations in the flame emissivity, as each of them affects the observation of radiation between roof and steel by the flame. The flame emissivity cannot, however, be reduced even as low as assumed[2] with flames 1 and 3 of Model 1 because the non-luminous emissivity of an actual flame, calculated from the accepted formulæ,[5, 6] will certainly be greater than 10%. However, the flame shape previously assumed,[2] *i.e.*, a laminar wedge spreading from a point at one end of the furnace to the full 14 ft. at the other, could certainly be altered without violating our knowledge of the facts. Thus Leys[7] has given flame patterns which only spread to about half the width of the furnace at the outgoing end, whilst in any furnace with knuckles in the front and back wall the flame width will certainly be reduced. It is therefore perfectly logical to try a model with a laminar flame spreading from a point at the ingoing end to half the width of the bath at the outgoing end.

Table I

EFFECTS OF REDUCTION IN FLAME WIDTH AND OF SLAG RESISTANCE

m = Fuel input rate, lb./hr.; η = Thermal efficiency, %; $t_{1\to3}$ = Time to melt 100 tons of steel, hr.; T_R = Temperature of roof and walls assumed only to vary with distance along furnace, °C.

Flame Type	m = 1000			m = 2000			m = 4000		
	η	$t_{1\to3}$	T_R	η	$t_{1\to3}$	T_R	η	$t_{1\to3}$	T_R
(*a*) Effect of Reduction in Flame Width (Model 3)									
Flame 1									
$f = 1$*	40·1	17·7	1563	44·3	8·0	1599	35·2	5·0	1625
$f = 0{\cdot}5$†	35·3	20·0	1544	32·0	11·1	1557	21·4	8·3	1565
Flame 2									
$f = 1$	40·9	17·3	1583	52·6	6·7	1655	57·6	3·2	1745
$f = 0{\cdot}5$	40·9	17·3	1586	52·6	6·7	1611	54·3	3·3	1671
Flame 3									
$f = 1$	29·1	24·4	1517	30·0	11·8	1529	22·5	7·9	1539
$f = 0{\cdot}5$	21·0	33·8	1516	19·5	18·1	1519	12·5	14·2	1529
Flame 4									
$f = 1$	38·3	18·5	1521	47·0	7·5	1565	47·1	3·8	1645
$f = 0{\cdot}5$	36·0	19·7	1517	45·0	7·9	1553	43·4	4·1	1623
(*b*) Effect of Slag Resistance, using 4-in. Steel Equivalent (Model 2)									
Flame 1									
$f = 1$	37·6	18·8	1840	33·0	10·8	1911			
Flame 3									
$f = 1$	21·6	32·0	1660	19·7	18·0	1743			
(*c*) Effect of Slag Resistance and Reduction in Flame Width, Using 1-in. Steel Equivalent (Model 4)									
Flame 1									
$f = 0{\cdot}5$				30·2	11·8	1653	19·9	8·9	1665

*$f = 1$ denotes flame spreading to full width of furnace at outgoing end (Models 1 and 2)
†$f = 0{\cdot}5$ denotes flame spreading to half width of furnace at outgoing end (Models 3 and 4)

This model (Model 3) is shown graphically in Fig. 1 and the results of the calculations with it are given in Table I*a* for all four types of flame, *viz.*,

Flame 1—Short flame with emissivity falling to 0·1 at one-third of furnace length

Flame 2—Short flame with emissivity maintained at 1 over the whole length

Flame 3—Long flame with emissivity falling to 0·1 at one-third of furnace length

Flame 4—Long flame with emissivity maintained at 1 over the whole length.

With the two higher-emissivity flames (2 and 4), the reduction of the flame width makes very little difference to the efficiency at any given fuel input rate and thus also to the efficiency. It does, however, cause a substantial lowering of the peak roof temperature at the higher rates of fuel input, which means that the higher fuel input rate can be used without overheating the roof. On the other hand, the two lower-emissivity flames, with the new model of narrower flame, now show characteristics which agree in regard to efficiency and melting time for the actual fuel input rates with the figures for a characteristic 100-ton furnace, *e.g.*,

Melting time t_{1+2}	= 9 hr.
Oil input rate	= 375 gal./hr. = 3560 lb./hr.
Efficiency	= 21·5%.

At such a rate the peak roof temperature would, however, be 1650° C., and not 1570° C. as given by flame 1 at 4000 lb./hr., or 1530° C. for flame 3.

Complete agreement between the model and practice can therefore be secured by incorporating a small amount of thermal resistance in the slag to bring the roof temperature to the value of 1650° C. without changing the melting time or efficiency very much. This is done in Model 4 of Table I*c*.

DISCUSSION AND CONCLUSIONS

(1) The only way to obtain a description of heat transfer in the oil-fired O.H. furnace which agrees with all the facts of (i) fuel input rate permitted by maximum roof temperature, (ii) melting time, (iii) thermal efficiency, is by making the following assumptions:

(*a*) The effective emissivity of the flames is nearer to that of flames 1 and 3 than to unity

(*b*) The effective flame shape is that of a laminar wedge spreading to not more than half the width of the furnace at the outgoing end

(*c*) The resistance to heat transfer through the slag cannot be greater than a value corresponding to about that of 1 in. of solid steel

(*d*) The flame taken in the model agrees with observed furnaces both for short and long flames (flames 1 and 3, respectively) according to whether the roof is observed to be hotter at the ingoing or the outgoing end.

(2) Any increase in the thermal resistance of the slag will be the most potent factor in forcing the operator to cut the fuel input rate to avoid overheating the roof and thus increasing the melting time. Conversely, if the thermal resistance of the slag is necessarily high, there will be the greatest benefit in using an all-basic roof which can be operated at a higher temperature.

(3) The best way to increase the thermal efficiency is to raise the flame emissivity, but this does not shorten the melting time if the roof is already running at the maximum temperature for the greater part of the melting time. However, on a furnace which is not tending to overheat the roof during melting, raising the flame emissivity will both save fuel and shorten the melting time.

(4) If the flame emissivity is necessarily low, it is very desirable to have the greatest possible coverage of the bath by the flame, as this will give a considerable saving in fuel to melt. With a long flame, increased bath coverage will also give a reduced melting time.

APPENDIX I

Allowance for Thermal Resistance of Slag Layer

It has been shown that, when no account is taken of the slag layer,

$$\overline{ns} = \frac{\overline{NS}}{1000} = k(T_f - T_s) - C \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The symbols are those used in the previous paper (*see* Thring, *op. cit.*,[2] p. 385, equation (5)).

The influence of the slag layer may be taken into account by including a thermal resistance term between the flame and the bath, which will involve an additional temperature term.

If

T_b = Temperature of the surface of the slag in a given zone, ° C.

ϕ = Thermal conductivity of slag or equivalent steel, C.H.U./sq.ft. hr. ° C. in.

α = Thickness of slag or equivalent steel, in.,

equation (1) can be rewritten:

$$\frac{\overline{NS}}{1000} = k(T_f - T_b) - C \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

and

$$NS = \frac{\phi}{\alpha}(T_b - T_s) \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

By eliminating T_b from equations (2) and (3), it can be shown that

$$\frac{\overline{NS}}{1000} = \frac{k(T_f - T_s) - C}{\left(1 + 1000\,\frac{k\alpha}{\phi}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

which may be written

$$\frac{\overline{NS}}{1000} = \frac{k(T_f - T_s) - C}{D} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where

$$D = 1 + 1000\frac{k\alpha}{\phi}.$$

The modified value of $\overline{NS}/1000$ from equation (5) is then substituted in the heat balance, which gives:

$$\Delta T_f \equiv \frac{\frac{m}{1000}\Delta x(15{,}660 - 5{\cdot}46T_{f1}) - 14\,\frac{k}{D}\Delta l(T_{f1} - T_s) - 56\Delta l + 14\,\frac{C}{D}\Delta l}{24{\cdot}5\,\frac{k}{D} + \frac{m}{1000}\left[1{\cdot}17 + 5{\cdot}46(x_1 + \Delta x)\right]}$$

Thus the terms involving k and C are divided by the factor D, which must be calculated for each section.

The necessary calculations can then be performed, although it is now necessary to calculate T_b in order to find T_R;

$$T_R = \epsilon g T_f + (1 - \epsilon g) T_b - 11 \quad \ldots\ldots\ldots\ldots (6)$$

The numerical values of α/ϕ to substitute in D can be found for different assumptions of equivalent slag thickness and thermal conductivity.

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The Metastability of Austenite in an 18/8 Cr–Ni Alloy

By B. Cina, B.Sc., Ph.D.

SYNOPSIS

The metastability of austenite in a commercial 18/8 Cr–Ni alloy has been investigated by metallographic, thermomagnetic, and room- and high-temperature X-ray diffraction methods. A measure of the extent of transformation $\gamma \rightarrow \alpha$ has been obtained for samples deformed in tension at room temperature to —196°C., and for softened and cold-worked samples after tempering at 500–800°C. It has been shown that the extent of austenite breakdown after tempering is primarily related to the loss of carbon by its precipitation as $(Cr.Fe)_{23}C_6$, and that this transformation $\gamma \rightarrow \alpha$ occurs only on cooling from the tempering temperature and below about 300°C. Isothermal ferrite formation at room temperature has been observed after sensitizing treatments. 1041

It is well known that when an initially austenitic 18/8 alloy is quenched after exposure at some temperature in the range 450–800°C. or is simply cold-worked without any such treatment, a body-centred cubic (B.C.C.) phase can subsequently be observed. Whilst the martensitic mode of formation of the B.C.C. phase observed after cold work is now established, there has been considerable controversy over that of the B.C.C. phase observed after tempering, some opinions[1–3] favouring its formation at tempering temperature, and others[4–7] on cooling.

The present work attempts to obtain a quantitative measure of the extent of austenite breakdown that can be obtained in a typical commercial 18/8 alloy by cold work and/or by tempering, and to correlate and explain these three factors.

MATERIALS USED

Hot-rolled bar ($1\frac{1}{8}$ in. dia.) was used throughout the investigation, and was of the following composition :

Alloy N760 : Composition, %

C	Si	Mn	S	P
0·12	0·55	0·34	0·019	0·020
Cr	**Ni**	**Mo***	**N**	
17·86	7·9	0·34	0·029	

* Residual.

The material was given a standard commercial softening treatment of 1 hr. at 1050°C., W.Q., and in this condition had the following mechanical properties :

Limit of proportionality, tons/sq. in.	7·55
0·05% proof stress, " " "	12·8
0·10% " " " " "	14·8
0·50% " " " " "	17·95
Maximum stress, " " "	44·0
Elongation, %	62·5
Reduction in area, %	68
Izod impact value, ft.lb.	120
Hardness, D.P.N.	172

DETAILS OF COLD WORKING AND TEMPERING

To study the effect of cold work (applied at room temperature) followed by tempering, tensile test pieces of overall length 9·5 in. and gauge length and diameter of 6 in. and 0·5 in., respectively, were machined from the bar after softening, and given permanent extensions of 5%, 10%, and 15%, respectively. Discs $\frac{1}{4}$ in. thick sawn from the gauge lengths of these cold-worked tensile test pieces were used for the tempering treatments. The latter consisted of $\frac{1}{4}$, 1, 4, and 24 hr., 1 week, and 1 month at 500°, 600°, 700°, and 800°C. Treatments at 200°, 300°, and 400°C. were also carried out. The samples were heat-treated in batches of four, representing 0%, 5%, 10%, and 15% permanent elongation, a separate sample being used for each tempering treatment. The immediate effect of applying the cold work at

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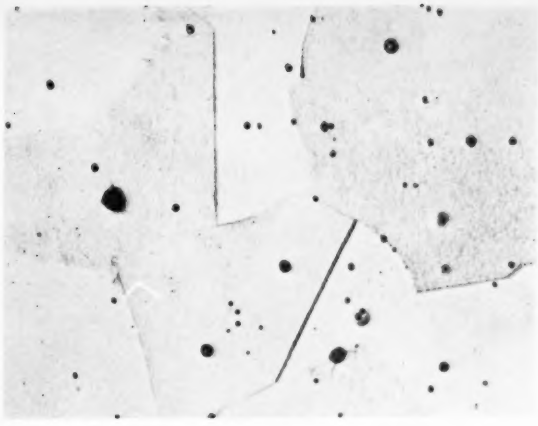
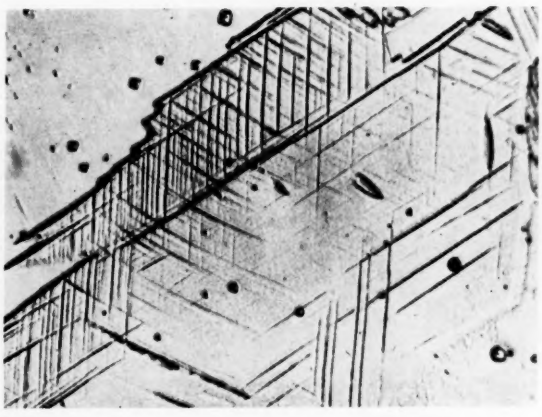
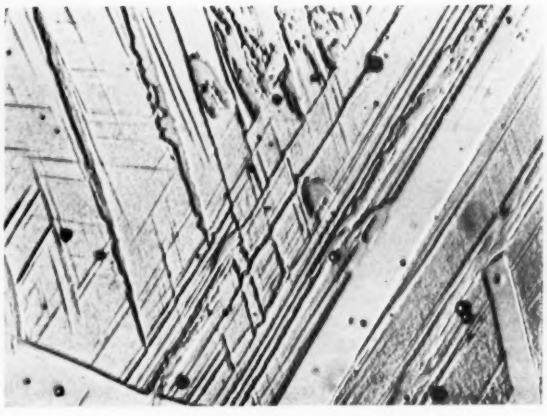
(*a*) As rolled



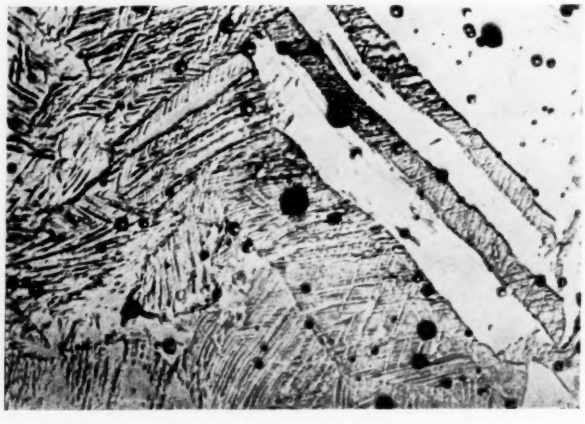
(*b*) 1 hr. at 1050° C., W.Q.



(*c*) 1 hr. at 1050° C., W.Q., + 5% elongation



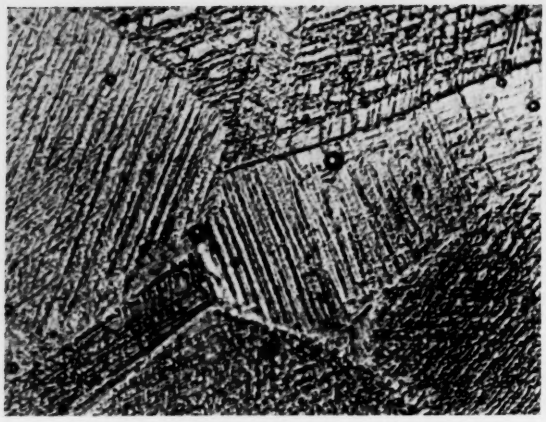
(*d*) 1 hr. at 1050° C., W.Q., + 10% elongation



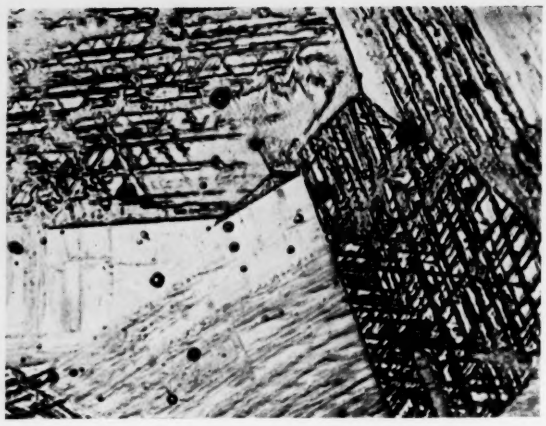
(*e*) ¼ in. behind tensile fracture (62·5% elongation)

Fig. 1—Samples of 18/8 alloy N760, electrolytically polished and etched electrolytically in 10% aqueous oxalic acid × 1500

[*Cina*
[*To face p.* 230

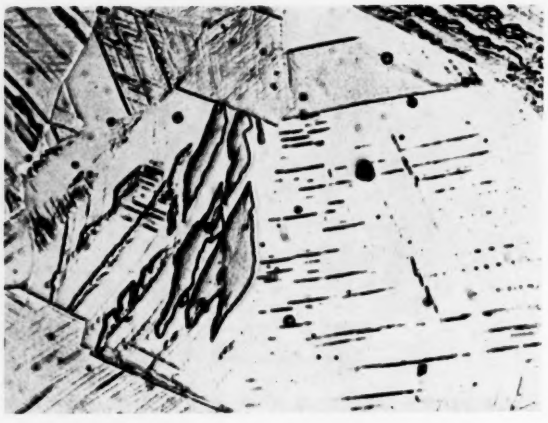


(*a*) 15% elongation at −183° C.



(*b*) 15% elongation at −50° C.

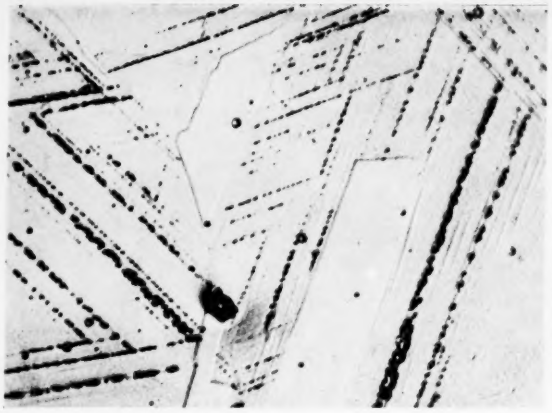
(*c*) 15% elongation at room temperature



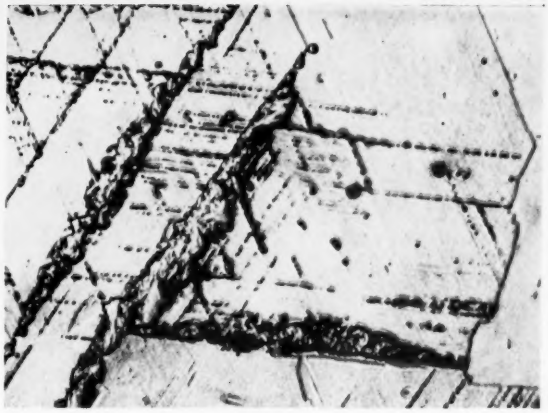
(*d*) 15% elongation + 1 week at 300° C., W.Q.

(*e*) 15% elongation + 1 week at 400° C., W.Q.

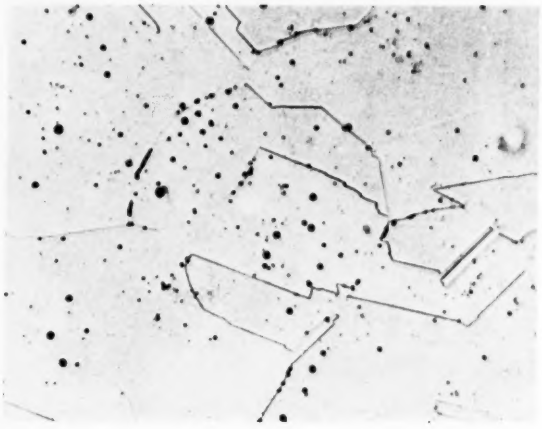
Fig. 2—Samples of 18/8 alloy N760, electrolytically polished and etched electrolytically in 10% aqueous oxalic acid × 1500



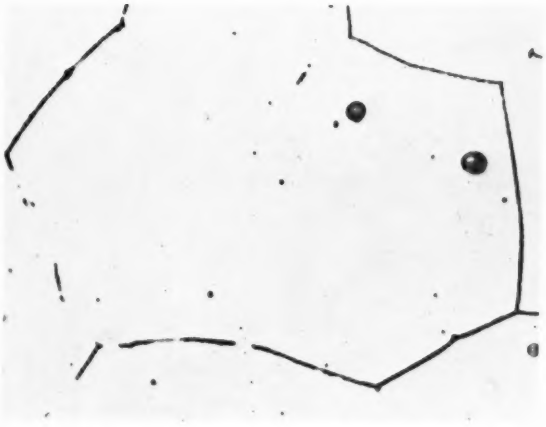
(*a*) 5% elongation + 24 hr. at 400° C., W.Q.



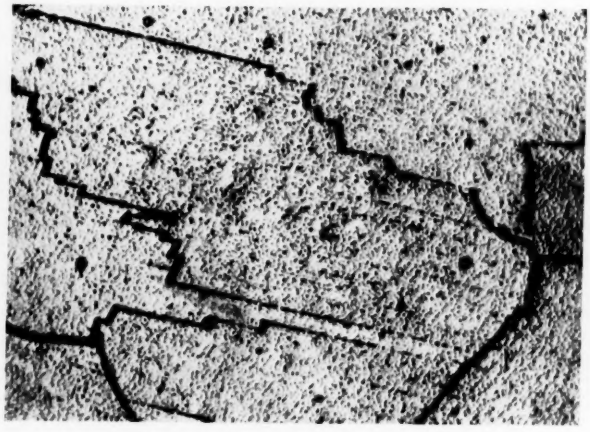
(*b*) 10% elongation + 24 hr. at 400° C., W.Q.



(*c*) 24 hr. at 500° C., W.Q.



(*d*) 1 week at 500° C., W.Q.

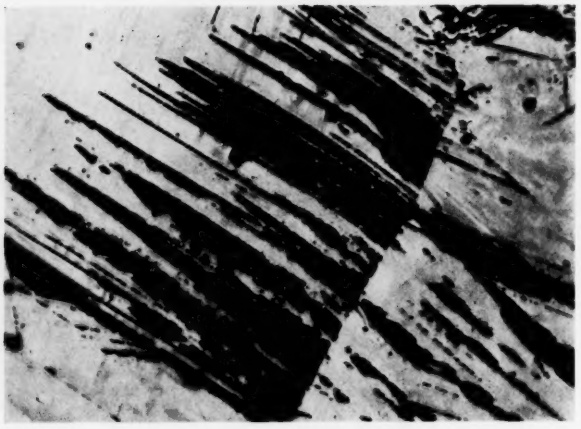


(*e*) ½ hr. at 700° C., W.Q.

Fig. 3—Samples of 18/8 alloy N760, electrolytically polished and etched electrolytically in 10% aqueous oxalic acid
(*a*), (*b*), (*d*), (*e*) × 1500, (*c*) × 500

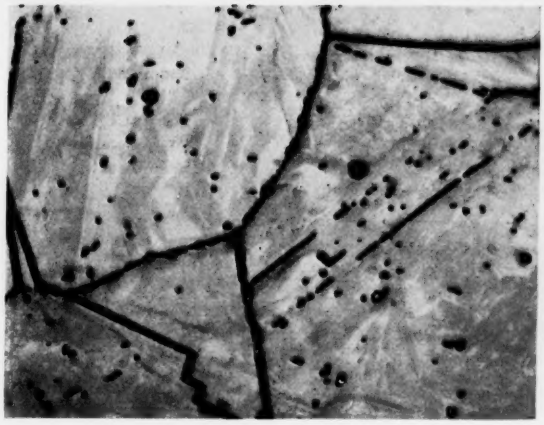
(*a*) 1 week at 700° C., W.Q

(*b*) 1 month at 700° C., W.Q.

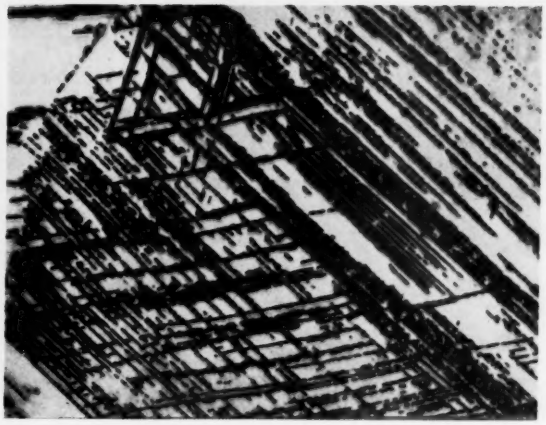


(*c*) 15% elongation + 1 week at 500° C., W.Q.

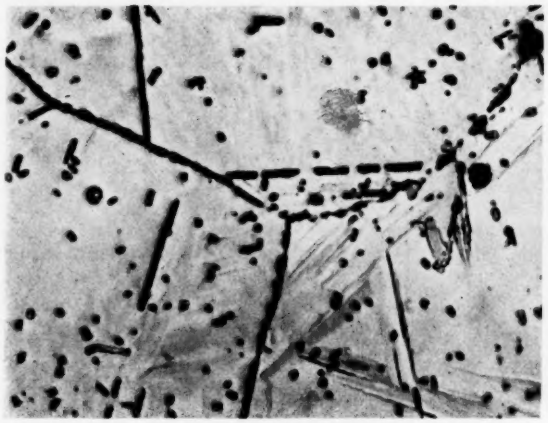
Fig. 4—Samples of 18/8 alloy N760, electrolytically polished and etched electrolytically in 10% aqueous oxalic acid (*a*) and (*b*) × 500, (*c*) × 1500



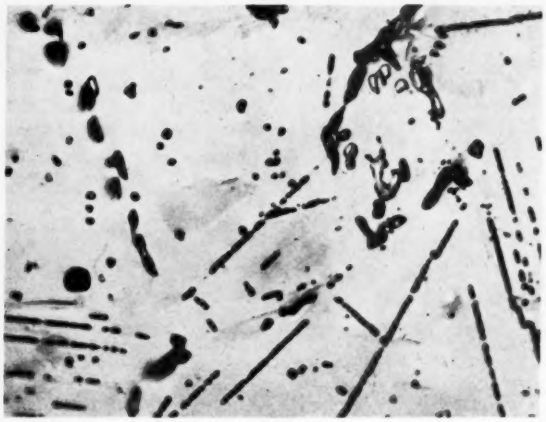
(*a*) 24 hr. at 800° C., W.Q.



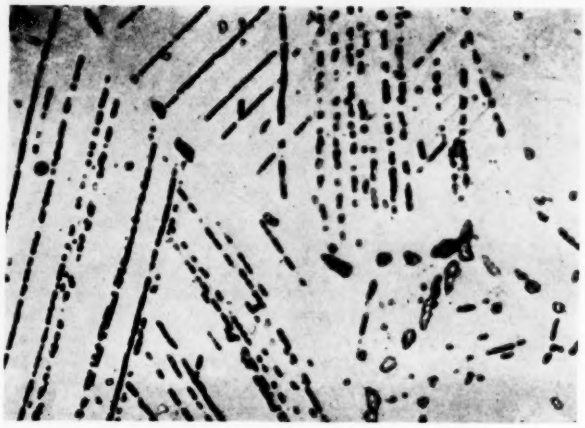
(*b*) 10% elongation + 24 hr. at 800° C., W.Q.



(*c*) 1 week at 800° C., W.Q.



(*d*) 1 month at 800° C., W.Q.



(*e*) 5% elongation + 1 month at 800° C., W.Q.

Fig. 5—Samples of 18/8 alloy N760, electrolytically polished and etched electrolytically in 10% aqueous oxalic acid × 1500

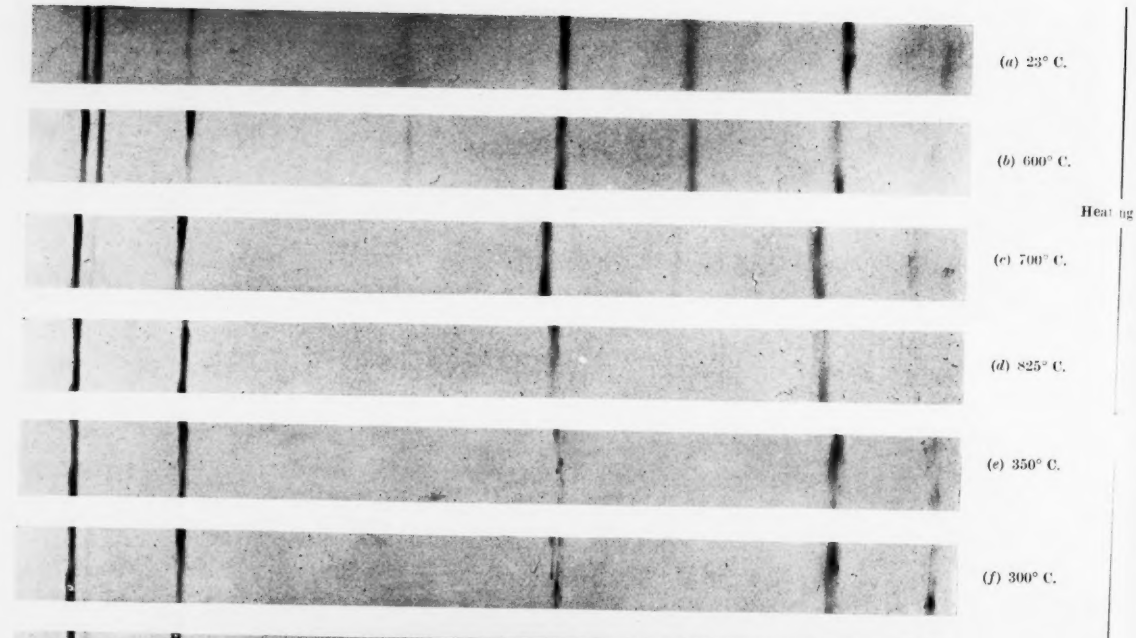


Fig. 6—High-temperature X-ray photographs of cast G5294 (18/8) Cr–Ni

−183°C. (in liquid oxygen) and at −50°C. (in CO_2–acetone) was also investigated, using tensile samples.

PREPARATION OF THE SAMPLES

After removal of scale by grinding and linishing, all samples were hand polished in the usual way to 000 emery paper on a transverse face, *i.e.*, at right-angles to the direction of the applied cold work. They were then electrolytically polished for 2 min. in a mechanically stirred bath operating at an applied voltage of 24 V. A 1 : 4 perchloric-acid–methyl-alcohol bath was used as electrolyte and a small piece of Staybrite steel sheet as cathode. The polishing bath was kept at −30° to −40°C. in the early part of the work, but was kept at room temperature in the later work. The samples were electrolytically etched in a 10% aqueous solution of oxalic acid for 15–30 sec., washed with water and acetone, and dried in a hot-air blast. The samples were examined microscopically and by X-ray diffraction in the electrolytically polished and etched condition.

DETAILS OF PHASE ESTIMATION

This was carried out by an X-ray diffraction method identical to that used previously,[8] in which the relative intensities of the γ and α spectra obtained by grazing-incidence technique from any sample are compared with those of standards. A 9-cm. dia. Debye-Scherrer camera, employing CoK_α X-radiation, was used for all such exposures. Where the grain size was such as to give spotty diffraction patterns, as in non-cold-worked samples, the latter were rotated during exposure to the X-ray beam. Phase estimations are considered to be accurate to ± 5% for values in the region of 50% and to ± 2% for values of 10% or below.

INITIAL MICROSTRUCTURES

As Rolled

In this condition, the material was seen to consist of twinned austenitic grains with undissolved chromium carbide particles occurring at the grain boundaries and within the grains, as shown in Fig. 1*a*.

As Softened : 1 hr. at 1050°C., W.Q.

A considerable number of the chromium carbides have now been taken into solution in the austenite, as can be seen from Fig. 1*b*.

EFFECT OF COLD WORK ON ALLOY CONSTITUTION

Many workers,[1, 2, 4–7] have shown that the effect of cold work on an alloy of the 18/8 type is to bring about a certain degree of transformation of the metastable austenite to ferrite. In the present investigation, examination by X-ray diffraction showed that about 5–10% ferrite was present after 15% extension at room temperature. This ferrite was observed in the microstructure as lath-shaped particles occurring on certain crystallographic planes of the austenite crystals the amount of these laths increasing with cold work, as shown in Figs. 1*c* and *d*. With small amounts of cold work (<5% permanent elongation), the ferrite occurred as thin plates. The apparent width of a ferritic lath would, however, be dependent to some extent on the angle at which it was sectioned. Figure 1*e* shows the greater amount of ferrite present in a transverse section taken adjacent to the fracture of a tensile test piece stretched 62·5% to rupture. Examination by X-ray diffraction near the point of fracture indicated that about 25% ferrite was present.

Table I

EFFECT OF TEMPERATURE OF APPLICATION OF COLD WORK

Permanent Extension, %	Temperature of Application of Cold Work, °C.	Ferrite by X-ray Diffraction, %
15	−183	60
15	−50	50
15	Room temp.	5–10
0	" "	0
5	" "	<5
10	" "	5
15	" "	5–10
62·5*	" "	25

* This value is an underestimate due to necking.

It is worth mentioning that false structures can be obtained in 18/8 alloys if electrolytic polishing is incorrectly carried out. Thus striations and very occasionally clusters of α ferrite particles were observed in softened samples when an attempt was made to polish electrolytically the entire $1\frac{1}{8}$-in. dia. bar section using the standard technique. The latter had here failed to remove adequate material cold-worked by the previous manual polishing. Small sections of the as-rolled or softened material, comparable in size with those used for the cold-working experiments, were successfully polished, as shown in Figs. 1*a* and *b*.

EFFECT OF TEMPERATURE OF APPLICATION OF COLD WORK

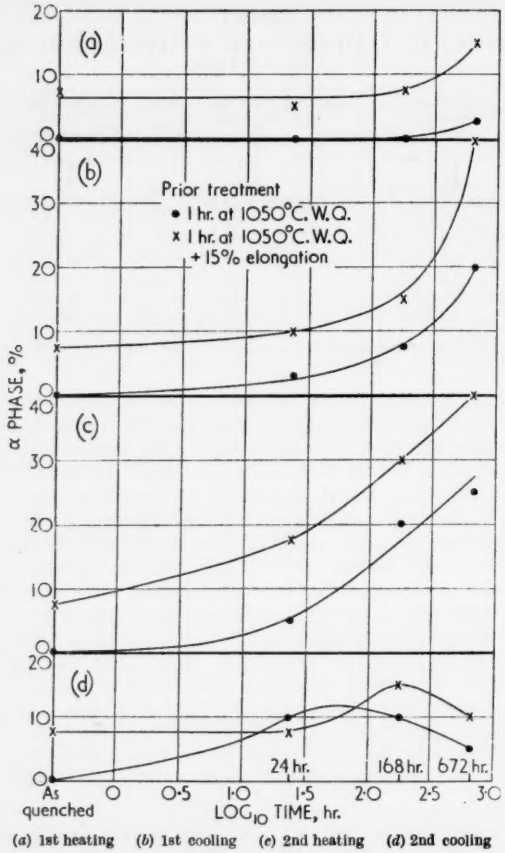
The results of this part of the investigation are summarized in Table I.

The amount of ferrite formed increased with the extent of deformation (at room temperature) and with a decrease in deformation temperature. Subjection to sub-zero temperatures was itself insufficient to transform austenite water-quenched from 1050°C. Thus, samples in (*a*) the softened and (*b*) the softened + 15% extended conditions showed the same amounts of ferrite, *i.e.*, 0 and 5–10%, respectively, after exposure for 1 hr. at −50°C. and for over 1 hr. at −183°C. Figures 2*a–c* show the decreasing percentage of ferrite in the microstructures of samples extended 15% at −183°C., −50°C., and room temperature, respectively.

EFFECT OF TEMPERING ON MICROSTRUCTURE

200–400°C.

No microstructural changes were observed in samples water-quenched from 1050°C. after periods up to 1 week at 200–400°C., nor in prior cold-worked samples tempered at 200°C. Cold-worked samples treated for 1 week at 300° or 400°C. showed carbide precipitation on the slip planes of the austenite and incipient or actual precipitation in the ferrite laths, respectively, as shown in Figs. 2*d* and *e*. Figures 3*a* and *b* reveal similar features in cold-worked samples after only 24 hr. at 400°C. Incipient precipitation is



(*a*) 1st heating (*b*) 1st cooling (*c*) 2nd heating (*d*) 2nd cooling

Fig. 7—Effect of tempering at (*a*) 500°C., (*b*) 600°C., (*c*) 700°C., (*d*) 800°C. on the constitution of an 18/8 Cr–Ni alloy

inferred from the readier response to etching of the ferrite laths.

500–700°C.

The effect of treatment in this temperature range was very marked. Samples prior treated at 1050°C. showed carbide precipitation on grain and twin boundaries. The continuity of this precipitate increased with tempering time and temperature, as shown in Figs. 3*c–e*. At 700°C., precipitation occurred also randomly in the grains, as shown in Figs. 3*e* and 4*a*, although it was always more pronounced near grain boundaries. Cold-worked samples showed very heavy carbide precipitation, especially on austenite slip planes, within the former ferrite laths, and to a lesser extent on grain boundaries, as in Fig. 4*b*. In addition, an acicular phase was observed in regions where carbide precipitation has occurred. This was identified by X-ray diffraction as α ferrite and is illustrated in Fig. 4*c*. Its mode of formation will be discussed later.

As a rough estimate of the relative rates of carbide precipitation at 400°, 500°, 600°, and 700°C., observations of the microstructures showed that for the initial periods of tempering and for the same prior degree of cold work, precipitation was about four times faster at 700° than at 600°C., about four times faster at 600° than at 500°C., and about 24 times faster at 500° than at 400°C. Diffusion calculations later gave values comparable with these.

800°C.

Carbide precipitation was more rapid at 800°C. than at lower temperatures and appeared in coarser form : Figs. 5*a* and *b* show the structure of softened and 10% cold-worked samples, respectively, after 24 hr. at 800°C. The former shows an almost continuous network of carbide at the austenite grain boundaries and the presence of α ferrite within the grains. In Fig. 5*b*, only a carbide precipitate marks the location of former ferrite laths (formed by cold work). After 1 week at 800°C. there was slightly more carbide precipitate within the grains of a former softened sample, as in Fig. 5*c*. After 1 month, the precipitate had coalesced somewhat in both softened and cold-worked samples, and σ was suspected in small amounts ($\ll 5\%$) at the grain boundaries, as shown in Figs. 5*d* and *e*. This σ may have formed from chromium carbide, as in 25/20 type alloys.[9] Less carbide was out of solution after 1 month at 800°C. than at 700° or 600°C.

RESULTS BY X-RAY DIFFRACTION

Extent of Austenite Transformation as a Result of Tempering

Owing to the poor etching contrast obtained between ferrite produced as a result of tempering and the parent austenite, resort was made to X-ray diffraction (grazing-incidence technique) to measure the amount of this ferrite. Figure 7 shows the extent of ferrite formation as a function of tempering time in softened and 15% extended samples after treatment in the range 500–800°C. The initial rate of ferrite formation increases with tempering temperature from 500° to 700°C. and the amount formed is greater at higher temperatures up to 700°C. The prior cold-worked

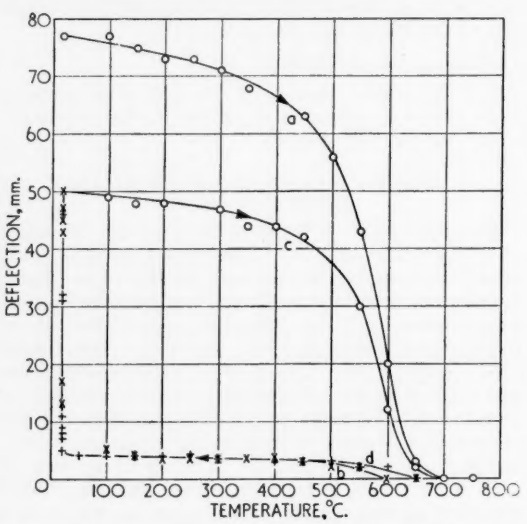


Fig. 8—Thermomagnetic changes in an unstable 18/8 Cr–Ni alloy

samples show consistently more ferrite than those in the prior softened condition, for temperatures of 500–700°C. The extent of ferrite formation would seem to be related to the amount of chromium carbide precipitated. This would explain why less ferrite was observed after 1 month at 800°C. than at 700° or 600°C., since less carbide was observed to be out of solution at 800°C. The first crossing of the curves in Fig. 7*d* is probably not significant, the difference between the two curves near this point being within the limits of experimental accuracy for phase determination. The final decrease in ferrite content in Fig. 7*d* can possibly be attributed to the re-solution of previously precipitated carbide particles, and to the homogenization of the matrix with respect to its carbon and chromium contents. Similar effects would be expected after much longer periods at temperatures lower than 800°C.

Identification of Precipitate Observed on Tempering

An electrolytic residue [10] was obtained from samples which had been extended 0% and 15% and tempered for 1 week at 500°, 600°, 700°, and 800°C. Chromium carbides and σ are insoluble in the electrolyte used. The residues were examined by X-ray diffraction (powder technique) in a 19-cm. Debye-Scherrer camera using MnK_α X-radiation. Only $(Cr,Fe)_{23}C_6$ was found in each.

FORMATION OF FERRITE OBSERVED AFTER TEMPERING

As there was controversy in the literature about whether the ferrite observed after tempering an unstabilized 18/8 steel formed at its tempering temperature or during subsequent cooling, an attempt was made to clarify the matter. This was tackled in three ways: (*a*) by thermomagnetic measurements; (*b*) by studying the approach to equilibrium at the tempering temperature; and (*c*) by high-temperature X-ray diffraction. The last-named is dealt with separately in the Appendix.

Thermomagnetic Measurements

For this work a magnetizing coil was wound round the thermal insulation of a small furnace. The coil was connected to a 5-amp. D.C. supply and was suitably water-cooled. The sample to be examined, in the form of a rod $\frac{1}{8}$ in. dia. × 1 in. long, was strapped to a thermocouple, placed inside a narrow silica tube, and the latter was wound with two identical magnetic search coils connected back to back. One coil enclosed the sample, the search coils being connected to a ballistic galvanometer. By reversing the current in the magnetizing coil, a deflection was obtained on the ballistic galvanometer proportional to the extent of magnetization of the sample. The field strength obtained was such as to give almost complete magnetic saturation of the sample. In this way, curves of deflection on the galvanometer against temperature, roughly corresponding to $\sigma_{H,T}/T$ curves, were obtained on heating and cooling, where $\sigma_{H,T}$ represents the magnetization per gramme of a sample in a field H and at a temperature T.

The sample for examination had a prior history as follows:

> Softened, 1 hr. at 1050°C., W.Q.; extended 15% at room temp.; tempered, 1 week at 700°C., W.Q.

In this condition the sample contained ~ 25% α ferrite. It was hoped to gain information about the stability of this ferrite at temperatures of 20–700°C.

Heating the sample at 150 C.deg./hr. to 750°C. gave a deflection/time curve as shown in Fig. 8*a*. The sample was then maintained at 700°C. for 17 hr. and was then cooled at 100 C.deg./hr. to room temperature and gave curve *b* in Fig. 8.

The almost complete irreversibility of the transition above 600°C., shown in Fig. 8*a*, indicates the transformation of $\alpha \rightarrow \gamma$ at or above this temperature, since a magnetic transition alone, as at a Curie point, would have been fully reversible. The vertical portion of the curve at 20°C. in Fig. 8*b* indicates the retransformation $\gamma \rightarrow \alpha$. The points on this vertical portion of the curve were obtained by maintaining the sample at room temperature for over 40 hr. immediately after cooling from 700°C., the continuous increase of deflection with time at constant temperature being shown in Fig. 9.

Reheating the sample at 150 C. deg./hr. to 750°C., holding at 700°C. for 16 hr., and cooling at 100 C. deg./hr. resulted in curves *c* and *d* of Fig. 8, which are similar to *a* and *b*.

The room-temperature isothermal $\gamma \rightarrow \alpha$ transformation was confirmed by X-ray diffraction. Thus, a sample quenched from 700°C. and containing 20–25% α, was reheated to 700°C. and on cooling, it was found to contain 10% α immediately on reaching room temperature. It showed 20% α after ageing for about a day. The sample was electrolytically polished at room temperature before each determination of α content by X-ray diffraction.

Finally, a sample austenitized at 1200°C. and given a precipitation treatment of 1 week at 700°C., W.Q., was reheated rapidly to 800°C., held for 1 hr. at this temperature, and then cooled. The cooling was interrupted at 50 or 100 C. deg. intervals, the sample being held for $\frac{1}{2}$ hr. at each temperature in an attempt to induce the transformation $\gamma \rightarrow \alpha$. No such transformation was indicated at temperatures down to

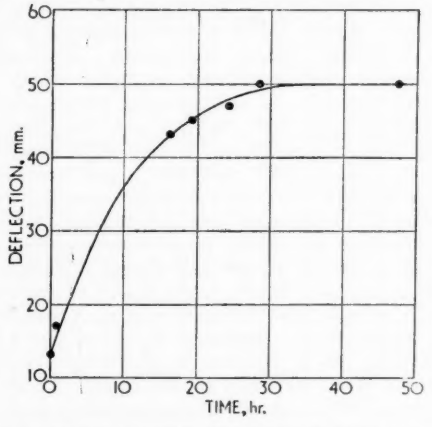


Fig. 9—Isothermal ferrite formation at room temperature as determined magnetically

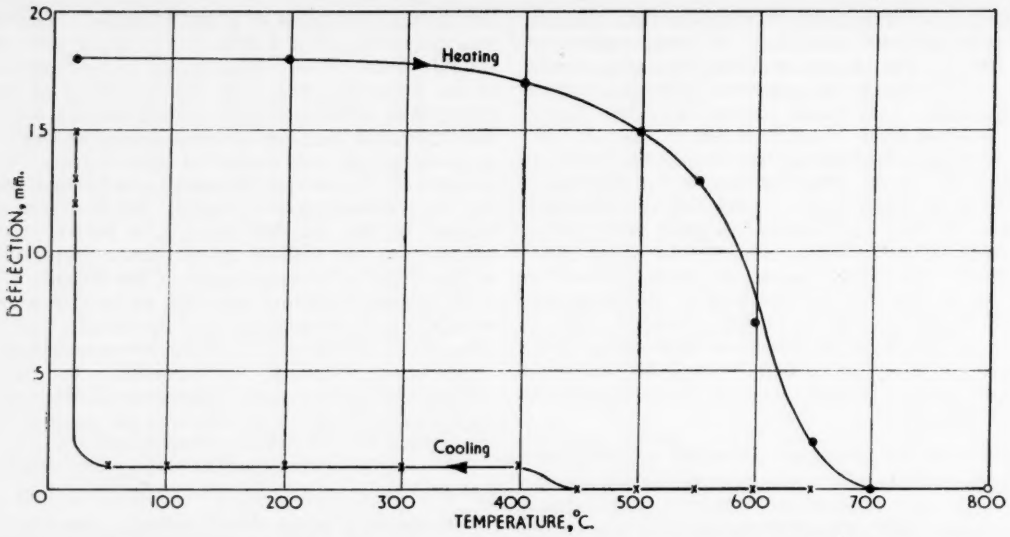


Fig. 10—Thermomagnetic changes in an unstable 18/8 Cr–Ni alloy : the effect of interrupted cooling

50°C., as shown in Fig. 10. A marked amount of transformation was, however, indicated at room temperature and proceeded isothermally as observed previously. Too much significance should not be attached to the deflection of 1 mm. recorded at 400°C. and below on cooling and not above this temperature, since the accuracy of the readings was only about $\pm 0{\cdot}5$ mm.

The results indicate that the greater part of the ferrite observed after tempering an 18/8 alloy at 700°C. forms on cooling, especially below about 50°C. The greatest extent of transformation occurs isothermally at room temperature. The incomplete recovery of the initial ferrite content on reaching room temperature, as in Figs. 8 and 10, is possibly due to a combination of a stabilization effect and to a reduction in quenching stresses, both developed by the relatively slow cooling.

To separate the effect of the Curie point of the α phase on heating from that of the $\alpha \rightarrow \gamma$ transformation, the sample from the previous experiment was subjected to a thermal cycle (shown in Fig. 11*b*), as in a separate investigation.[11] In this, the sample was heated in stages to 700°C., the heating being interrupted after each stage by an intermediate cooling to 300°C. Readings of deflection were obtained after 5 min. at each temperature. Since the previous experiments had shown a temperature of 300°C. to be below the Curie point of the ferrite, cooling of the sample from any higher temperature to 300°C. and remeasuring the deflection would indicate how much ferrite was still untransformed at the higher temperature. Thus, any decrease in deflection at higher temperatures could be distinguished as being due to transformation ($\alpha \rightarrow \gamma$) or to a Curie point. For the latter only, the deflection would be recovered at 300°C. For transformation to have occurred, there would be incomplete recovery. No $\gamma \rightarrow \alpha$ transformation could occur on cooling to 300°C., since this transformation begins only below 50°C. The results are illustrated in Fig. 11*a*. The open circles O show the typical decrease in deflection of a duplex ($\gamma+\alpha$) sample on heating to 700°C., whilst the crosses + show the extent of recovery of magnetization and, therefore, the amount of ferrite still present on intermediate cooling to 300°C. from the several temperatures indicated at each cross. No transformation had occurred on heating to 400° or 500°C. but it had begun at 550°C. The transformation proceeded on further heating, and was almost and finally fully complete after 5 min. and 1 hr., respectively, at 700°C. The progress of this transformation is illustrated in Fig. 12.

Approach to Equilibrium at Tempering Temperatures

Since it had been found that a greater degree of the transformation $\gamma \rightarrow \alpha$ occurred by cold-working the alloy at sub-zero temperatures, it was considered that samples which had been so treated would be nearer equilibrium than non-cold-worked material and might afford information about the stability of ferrite at the tempering temperatures. Samples which had been extended 15% at −183°C. and which in consequence contained 60% ferrite, were tempered for periods of up to 1 month at 700° and 800°C. and up to about 2 weeks at 500° and 600°C., and were water-quenched. The percentage of ferrite present in each sample after tempering was determined by X-ray diffraction and the results are plotted in curves 1–4 in Fig. 13. Curves 1–3 show that after 1-hr. tempering at 800°, 700°, and 600°C. more than half the ferrite in each sample has retransformed to austenite at those temperatures. Further tempering up to 1 week at 700° and 800°C. resulted in an increase in ferrite content. If the 40% and 15–20% ferrite found after 1 week at 700° and 800°C., respectively, had been stable at those temperatures, the ferrite content at those temperatures should not previously have

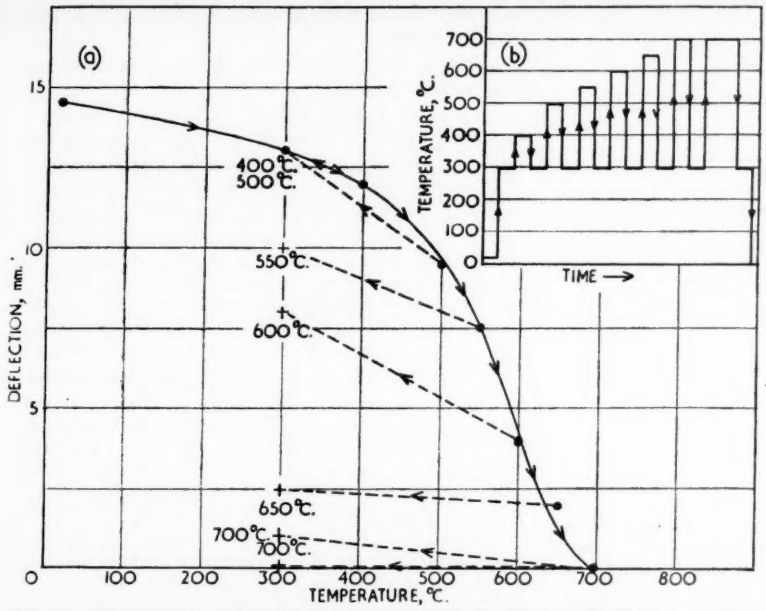


Fig. 11—Thermomagnetic changes in an unstable 18/8 Cr–Ni alloy : separation of Curie point and allotropic changes

dropped below those values. One would have expected it to be easier for equilibrium to be attained by the precipitation of chromium carbide from the original 60% ferrite, leaving relatively carbon-free ferrite, than by the retransformation of the ferrite to austenite and by precipitation of carbon from the latter, and subsequent transformation of this austenite to ferrite at the tempering temperature. It is suggested from these curves that the increase in the amount of ferrite observed between tempering periods of 1 hr. and 1 week at 700° and 800°C. is due to ferrite which has formed on quenching from the tempering temperature as a result of carbide precipitation from austenite at the tempering temperature. This $\gamma \rightarrow \alpha$ transformation will be discussed later. The minima on the curves could represent either the small amounts of ferrite stable at the tempering temperature, or the amount of ferrite produced on quenching as a result of the limited structural changes taking place in a fully austenitic sample in 1 hr. at those temperatures. In the latter case, it is assumed that the initial ferrite completely transforms to austenite at the tempering temperatures of 700° and 800°C. Curve 3 in Fig. 13 shows a continuous decrease in ferrite content for periods up to about a fortnight at 600°C., whilst curve 4 shows that the approach to equilibrium is very much slower at the lowest temperature (500°C.), although once transformation of $\alpha \rightarrow \gamma$ has begun, it proceeds more rapidly.

DECREASE IN AUSTENITE STABILITY

The results of these last groups of experiments, together with those in the Appendix, indicated that either all or the greater part of the ferrite observed after tempering has formed not at the tempering temperature, but on subsequent cooling to room temperature. The stability of the austenite below 300°C. was, however, reduced either by holding the sample at a specific temperature in the range 500–800°C. or by slow cooling through that range.

In a commercial 18/8 steel, carbon is known to be the most powerful austenite stabilizer of the normal alloying elements present, whilst chromium has recently been shown[11] also to stabilize austenite at levels of 16–18% and in the presence of 8% of nickel. Micro-examination had shown that considerable amounts of chromium carbide had been precipitated during tempering, especially in prior cold-worked samples. Austenite, impoverished with respect to carbon and chromium, would be less stable and would have a very definite tendency to transform on cooling. For the precipitation of this carbide to have occurred, diffusion of carbon and possibly also of chromium

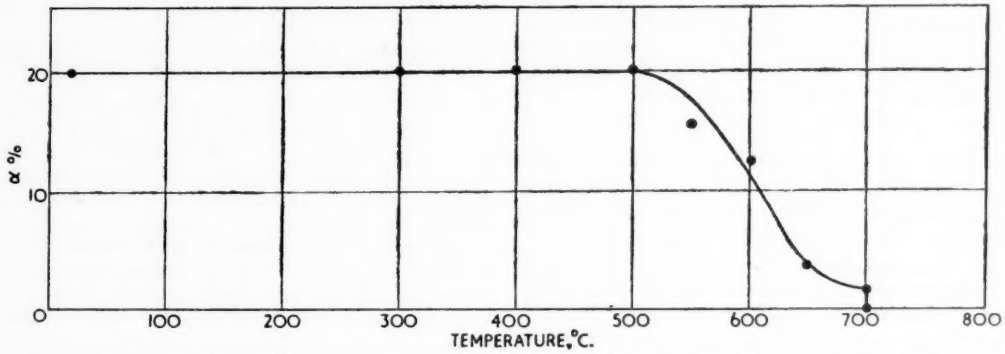


Fig. 12—Extent of transformation $\alpha \rightarrow \gamma$ on heating an unstable 18/8 Cr–Ni alloy as determined thermomagnetically

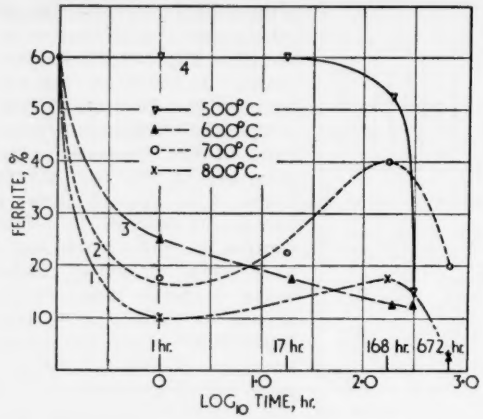


Fig. 13—Approach to equilibrium of an 18/8 Cr–Ni alloy at 500–800°C.

would have been essential. Some calculations were therefore carried out to determine the time necessary for the diffusion of carbon and chromium at tempering temperatures of 500–800°C., and the availability of chromium to combine with the carbon to form $Cr_{23}C_6$ at the several positions at which this compound was precipitated with a view to learning the extent and place of alloy depletion.

CALCULATIONS OF TIMES OF DIFFUSION OF CARBON AND CHROMIUM IN TEMPERED COLD-WORKED MATERIAL

These calculations are based on the following assumptions :

(i) That the diffusion of alloying elements is similar to that of heat and that the results of heat-flow calculations may be applied. The diffusion of heat through a plate of infinite length has been considered by Russell[12] and may be applied to the present problem. The symbols used by Russell will be used in the present paper.

(ii) That, on tempering, the chromium carbide precipitated on the slip planes is such as instantly to reduce to zero the carbon content of the immediately adjacent material so that a concentration gradient is established. Initially this has maximum carbon content halfway between the slip planes and zero carbon content adjacent to the slip planes. This is equivalent to the example in the heat-flow analogy, in which a plate of infinite length and initial uniform temperature is placed in a medium of different temperature such that the surfaces of the plate instantaneously adopt the temperature of the medium. Diffusion of carbon towards the slip planes is assumed because of the maintenance of a concentration gradient.

(iii) That the distance over which the carbon and chromium have to diffuse, at least in prior cold-worked material, is equal to half the distance between the slip planes on which precipitation is observed, the latter distance being taken as $13{\cdot}4 \times 10^{-5}$ cm., an average value obtained from a study of the microstructures of tempered cold-worked samples.

(iv) That the diffusion of carbon and chromium takes place in austenite.

(v) Wells and Mehl[13] give a value of $(0{\cdot}07 + 0{\cdot}06X\%C) \times e^{-32,000/RT}$ for the diffusion coefficient of carbon in austenite in heat-treating or carburizing steels for a range of carbon contents between 0·1 and 1·0 wt.-% and for a temperature range of 750–1250°C. Their work shows that nickel, present to the extent of 20%, causes only a slight increase in the value of $D_C{}^{\gamma Fe}$* at 1000°C. for a carbon content of 0·12% ; 8% nickel, as in the present alloy, would have an even smaller effect on $D_C{}^{\gamma Fe}$. As to the presence of 18% chromium, in the present alloy, it is assumed that because this element also forms a substantial solid solution with iron and has similar atomic dimensions, it will have no very great effect on $D_C{}^{\gamma Fe}$. For these reasons the value $D_C{}^{\gamma Fe} = 7{\cdot}0 \times 10^{-2}e^{-32,000/RT}$ has been used as a first approximation in the diffusion calculations.

(vi) Because of the absence of reliable data for $D_{Cr}{}^{\gamma Fe}$, the value $D_{Fe}{}^{\gamma Fe} = 5{\cdot}8 \times e^{-74,200/RT}$ obtained by Birchenall and Mehl[14] has been used as an approximation for $D_{Cr}{}^{\gamma Fe}$ because of the similarity and relationship between iron and chromium atoms as detailed above.

CALCULATION OF TIME REQUIRED FOR ALL THE CARBON TO DIFFUSE TO SLIP PLANES

From Russell's[12] tables (case 1) for the condition where the surface of the plate instantly adopts the same concentration of the alloying elements as its surroundings (*i.e.*, zero in this case, because the carbon is precipitated at the slip plane which defines the surroundings), the concentration at the centre of the plate approaches zero to within 0·1% of its initial concentration when $\tau = 3{\cdot}0$

Now
$$\tau = \frac{D \times t}{L^2} \qquad \text{.....(1)}$$

where D = Coefficient of diffusion
t = Time, sec.
L = Distance, cm., in which the diffusion occurs, *i.e.*, ½ × distance between slip planes.

From equation (1) the value of t has been calculated for temperatures of 500°, 600°, 700°, and 800°C. and the results are quoted in Table II.

ASSUMPTION FOR DIFFUSION OF CHROMIUM

It is assumed for the sake of the calculations that the chromium required to precipitate the carbon as $Cr_{23}C_6$ diffuses with the carbon to the slip planes and that a concentration gradient for chromium exists as for carbon. The proportion of chromium atoms diffusing with the carbon may then be calculated as follows.

The atomic percentages of chromium and carbon in the alloy are 18·92 and 0·55, respectively. Considering the diffusion as occurring over a front of area 1 sq. cm. and length L cm., and that in this volume of

* The symbol $D_x{}^{\gamma Fe}$ signifies the coefficient of diffusion of an element x in γFe.

$(1 \times L)$ c.c. there are N atoms per c.c., the total number of carbon atoms present $= N \times L \times 0{\cdot}0055$, and the number of chromium atoms required to combine with all the carbon atoms to form $Cr_{23}C_6$

$$= \frac{N \times L \times 0{\cdot}0055 \times 23}{6} = 0{\cdot}0211 \times N \times L.$$

Total number of chromium atoms present $= N \times L \times 0{\cdot}1892$ ∴ proportion of chromium atoms required to combine with all the carbon

$$= \frac{0{\cdot}0211 \times N \times L}{0{\cdot}1892 \times N \times L} \times 100 = 11{\cdot}15\%.$$

Using Russell's data, this proportion of 11·15% of the chromium atoms diffusing to slip planes was calculated to correspond to a value of τ of 0·007. Then, applying equation (1), taking $D_{Cr}^{\gamma Fe} = 5{\cdot}8 \times e^{-74{,}200/RT}$, $\tau = 0{\cdot}007$, and $L = 0{\cdot}000067$ cm., the values of t were calculated for temperatures of 500°, 600°, 700°, and 800°C., the results being given in Table II.

The outstanding feature in Table II is the considerably slower rate of diffusion of chromium as compared with that of carbon. This implies that the carbon, in order to be precipitated on the slip planes as $Cr_{23}C_6$, cannot be dependent on the requisite chromium diffusing with it, and must, therefore, combine with chromium which is already available at the precipitation sites. This is further borne out by the last column in Table II, which gives the times (estimated by observation of the intensity of precipitation) in which the greater amount of carbide to be precipitated has already done so. Whilst these latter estimates are in every case longer than the calculated times for diffusion of carbon, they are considerably shorter than the diffusion periods for chromium. The main bulk of the matrix, therefore, retains all or the very greater part of its chromium content while the carbon is being precipitated so that the decrease in stability of such zones cannot be due to impoverishment in chromium but is probably due to loss of carbon. This is in keeping with the known vastly greater stabilizing effect of carbon than chromium on austenite. The instability of a carbon-free 18/8 Cr–Ni austenite on quenching has been established elsewhere.[11]

EFFECT OF COLD WORK AND TEMPERING ON HARDNESS

The work-hardening characteristics in compression of the 18/8 alloy used in this investigation and the correlation between plastic deformation, work hardening, and allotropy for several Fe–Ni–Cr alloys have already been published.[11] Two additional series of experiments are, however, worth reporting, namely, the effect on hardness of applying plastic deformation in tension at temperatures of −196° to 20°C., and the effect on hardness of cold work followed by tempering.

Table II
CALCULATED AND OBSERVED DIFFUSION RATES

Temperature, °C.	Time to Diffuse 0·000067 cm. All the Carbon Atoms	Time to Diffuse 0·000067 cm. 11·15% of the Chromium Atoms	Time in which the Greater Part of $Cr_{23}C_6$ Precipitation has Occurred, as Observed Microscopically, hr.
	min.	hr.	
500	31	1,000,000	24
600	3	5000	1
700	0·5	55	1
800	0·1	14	¼

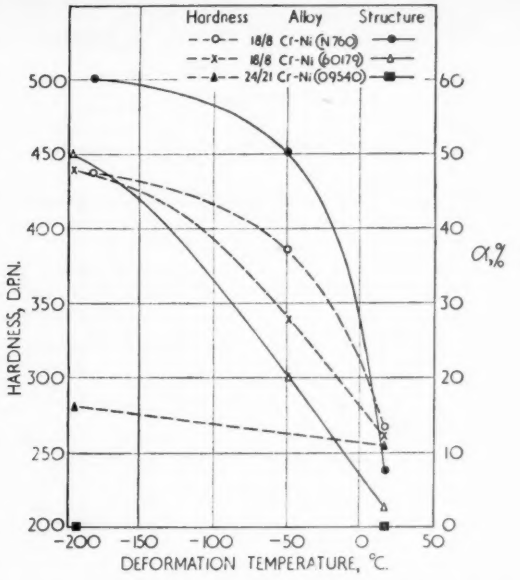


Fig. 14—Effect of deformation at room temperature to −196°C. on the constitution and hardness of three stainless alloys

PLASTIC DEFORMATION IN TENSION AT −196° TO 20°C.

Three alloys were used for this work : (1) the 18/8 alloy N760, used for the preceding experiments, (2) a less metastable austenitic 18/8-type alloy (cast No. 60179), and (3) a stable austenitic 24/21-type alloy (cast No. 09540). The compositions of all the alloys are given in Table III.

The effect on hardness and alloy constitution of applying 15% plastic deformation in tension at −196°C., −50°C., and room temperature on all three alloys is illustrated in Fig. 14. The hardness of the alloys in the condition 1 hr. at 1050°C., W.Q. was 172, 181, and 168 D.P.N., respectively. The marked increase in hardness in the two 18/8 alloys at sub-zero temperatures clearly results from the martensitic formation of ferrite. This increase is the more marked since the ferrite forms from an austenite containing about 0·1% of carbon in solution. The hardness increase for the 18/8 alloys between room temperature and −50°C. is more marked than between −50° and −196°C. This is discussed elsewhere.[11]

Effect of Cold Work Followed by Tempering on Hardness

The results of this part of the investigation are plotted in Fig. 15. Samples in the 0%, 5%, 10%, and 15% permanently elongated condition tempered for 1 week at 200°C., 300°C., and 400°C. showed no

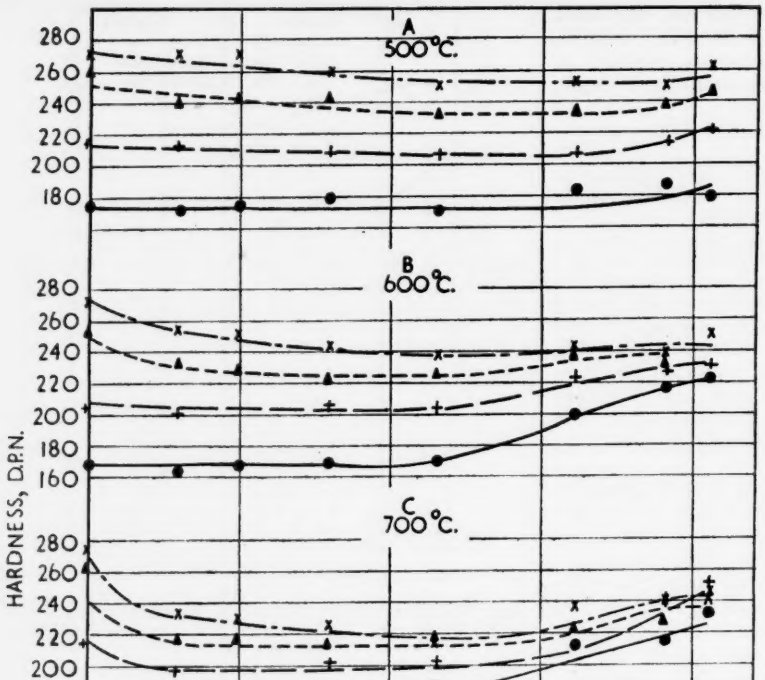


Fig. 15—Effect of tempering at (*a*) 500°C., (*b*) 600°C., (*c*) 700°C., (*d*) 800°C. on hardness of an 18/8 Cr–Ni alloy

significant change in hardness after any of the tempering treatments. That is in keeping with their microstructures.

The most significant features of Fig. 15 may be summarized as follows. The immediate result of tempering temperature is to bring about softening of the cold-worked material, the degree of softening increasing with tempering and being most marked in the sample given the most prior cold work. This softening effect occurs mainly within the first ¼ hr. of tempering at 600°C. and above, and thereafter continues at a decreasing rate for about 24 hr. at temperature. A hardening effect becomes apparent with further tempering and there is a suggestion at 600°, 700°, and 800°C. that the samples are approaching equilibrium, as shown by the several samples tending towards the same final hardness. At 500°C., the approach to equilibrium is much slower, and even after 2 months (1344 hr.) at 500°C. there is still a marked difference in hardness between the samples of this series.

The following explanations are offered for the hardness characteristics observed.

(*a*) *Prior Cold-Worked Material*—The initial marked softening of the cold-worked samples is due to stress relief of the austenite, and to the partial (at 600°C.) or complete (at 700° and 800°C.) disappearance of the original martensitic α phase containing about 0·05–0·1% carbon in solution. This stress relief is accompanied and followed by the precipitation of chromium carbides from both the austenite and original α phase (at 500° and 600°C.). The hardening due to this precipitation is initially masked by the stress-relief effects up to about 24 hr. at temperature; thereafter the former phenomenon becomes dominant because stress relief is almost complete, and an increase in hardness is observed. This explanation is confirmed by X-ray diffraction (back-reflection) examination, which showed a 15% extended sample to be still in a stressed condition after 1 week at 500°C., to be almost fully stress-relieved after 24 hr. at 600°C., and to be fully stress-relieved after 4 hr. at 700°C., indicating that at least after those times at 600° and 700°C. the hardness values obtained were not due directly to the cold work, but to the microstructural changes which it had induced on subsequent tempering. Finally, the difference in hardness between samples cold-worked to different extents, even after the cold-work effects have been removed, is simply due to the greater amounts of carbide precipitated in the more cold-worked samples. Eventually, these differences tend to be eliminated at 600°C. and above.

(*b*) *Prior Softened Material*—Softened samples begin to show a significant hardness increase only when the amount of carbide precipitated in them becomes appreciable.

A NOTE ON INTERCRYSTALLINE CORROSION

An unstabilized steel (*i.e.*, one containing no element such as niobium or titanium with a greater affinity for carbon than chromium) would not be recommended for use at temperatures in the range 500–800°C. because of the susceptibility to intercrystalline corrosion that might be developed.

Table III

COMPOSITION OF ALLOYS, wt.-%

Cast No.	C	Si	Mn	S	P	Cr	Ni	Mo	N
N760	0·12	0·55	0·34	0·019	0·020	17·86	7·9	0·34	0·029
60179	0·14	0·71	0·40	0·017	0·022	18·68	8·52	0·21	0·029
09540	0·10	1·70	0·75	0·007	0·021	22·96	21·0	..	..

DISCUSSION

An aspect of the present work round which perhaps the most discussion has centred in the past twenty years is that concerned with the formation of the ferrite phase observed after tempering a commercial 18/8 alloy at temperatures of 400–800°C. In 1930, Krivobok and Grossman[1] put forward the view that this ferrite phase was formed at the treatment temperature, an opinion which was also shared later, though for different reasons, by Beckett[2] (1938), and as late as 1945 by Clark and Freeman.[3] Since the early 1930's, however, information has accumulated which supports the theory of ferrite formation mainly on cooling from the treatment temperature. Thus, Krivobok and Gensamer[4] detected the $\gamma \rightarrow \alpha$ transformation at subzero temperatures in 18/8 very low (0·01–0·05%) carbon alloys by dilatometric methods on slow cooling from about 1000°C. No such transformation was observed when the alloy contained 0·13% of carbon ; *i.e.*, the additional carbon had further depressed the M_s point of the $\gamma \rightarrow \alpha$ transformation. From magnetic measurements, Buehl, Holloman, and Wulff[5] also concluded that α formed on cooling ; they said this occurred below 600°C. and because of the strains imposed by a carbide precipitate on the austenitic matrix. Uhlig,[6] working with a 0·007% carbon alloy, found a temperature hysteresis for the $\gamma \rightleftharpoons \alpha$ transformation of about 600 C. deg., the transformation $\gamma \rightarrow \alpha$ being observed by dilatometric methods to occur martensitically at 90–125°C. These later results were recently confirmed by the author[11] by thermomagnetic measurements on an alloy of purity similar to that of Uhlig.[6] A similar temperature hysteresis of transformation $\gamma \rightleftharpoons \alpha$ was observed dilatometrically by Smith *et al.*[15] in a 17/7/Ti/Al precipitation-hardening alloy, and was confirmed recently by Colner and Zmeskal[16] by electrical resistivity measurements. Dulis and Smith,[7] using high-temperature X-ray diffraction and magnetic methods, showed that ferrite forms as a consequence of sensitizing and on cooling to room temperature ; $\gamma \rightarrow \alpha$ was found to occur martensitically only below 260°C., there was a temperature hysteresis of about 600 F. deg. for the transformation $\gamma \rightleftharpoons \alpha$, and not more than 5% of ferrite was stable at 650°C. There was a suggestion that the latter 5% ferrite was that observed at the grain boundaries, whilst the ferrite formed martensitically below 260°C. appeared in Widmanstätten form within the grains.

The present work, including that in the Appendix, is in substantial agreement with that of Dulis and Smith,[7] confirming that the bulk, if not all, of the ferrite observed after treatment at 500–800°C. forms only on cooling to room temperature. The $\gamma \rightarrow \alpha$ transformation as observed magnetically in the N760 alloy was found to occur below 50°C. and especially isothermally at room temperature, although it did not proceed to completion at this temperature. Similar isothermal α formation was observed in pure 16/8 and 18/8 alloys.[11] The $\alpha \rightarrow \gamma$ transformation in the N760 alloy was likewise shown to begin above about 500°C. and to be complete at 700°C., indicating a temperature hysteresis of about 500–700 C.deg. in the transformation $\gamma \rightleftharpoons \alpha$. For the G5294 alloy in the Appendix, $\gamma \rightarrow \alpha$ began between 350° and 300°C., whilst $\alpha \rightarrow \gamma$ began between 600° and 700°C. The essential feature of α formation occurring on cooling well below the sensitizing range was again demonstrated. The large quantities of ferrite observed after long sensitizing treatments at 700° or 800°C. were shown to be unstable at those temperatures.

Acknowledgments

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APPENDIX

High-Temperature X-Ray Diffraction Examination of an 18/8 Cr–Ni Alloy

By B. Cina, B.Sc., Ph.D., and J. D. Lavender

Since the work reported in the paper was completed, a high-temperature X-ray diffraction unit has been constructed (by J. D. L.). The sample for examination is roughly in the shape of a tensile test piece of overall length 4½ in., gauge length 2 in., and gauge diameter ⅛ in. This sample is directly heated by the passage of A.C., the temperature being measured by a chromel/alumel thermocouple spot-welded to the gauge length at a point at opposite diameter to that being irradiated. Temperature variation is obtained by adjusting a resistance in series with the primary of a transformer in the circuit. Since exposure times to obtain a suitable diffraction pattern are of the order of only about 5 min., no special temperature controller is used, temperature being maintained constant to ± 5 C. deg. by manual control. The sample can be heated to any temperature in the range 20–1100°C. within 30 min., thermal equilibrium being attained within a few minutes. The sample is held for 15 min. at temperature and then examined by a simple grazing incidence technique. The whole assembly is evacuated during high-temperature heating to a pressure of $\sim 10^{-3}$ mm.

Owing to shortage of material of the 18/8 alloy N760 used in the previous investigation, a high-temperature X-ray sample was prepared from a further 18/8 alloy of the following composition :

Cast No. G5294 : Composition, wt.-%

C	Si	Mn	S	P
0·06	0·98	0·33	0·006	0·011
Cr	**Ni**	**Mo**	**N**	
17·18	7·88	0·01	0·015	

This material had been chill-cast as a 1¼-in. square ingot, forged to ⅝-in. square bar, and softened by treatment of 1 hr. at 1050°C. and W.Q. In this condition the material was fully austenitic. A further treatment of 1 week at 700°C., W.Q., resulted in the appearance of 25% ferrite as revealed by examination by X-ray diffraction at room temperature. This figure was obtained from a test piece machined from the 700°C. treated bar and electrolytically polished before examination. The test piece gave a strong response to a hand magnet, confirming the presence of the ferrite phase. Micro-examination showed this ferrite to be acicular α. The appearance of the latter after tempering at 700°C. thus showed this alloy to be similar in its transformation characteristics to the 18/8 alloy (N760) used previously.

Figure 16 shows the effect of heating this initially duplex sample (γ+25% α) to temperatures of 500–850°C. The α phase is seen to be stable for the periods employed at 500° and 600°C. but to undergo progressive transformation at 700–850°C. Holding the sample for 70 min. instead of the usual 10 min. at 700°C. had no effect on the amount of α ferrite present. Figures 6*a–d* show the high-temperature X-ray diffraction (glancing angle) photographs obtained on heating

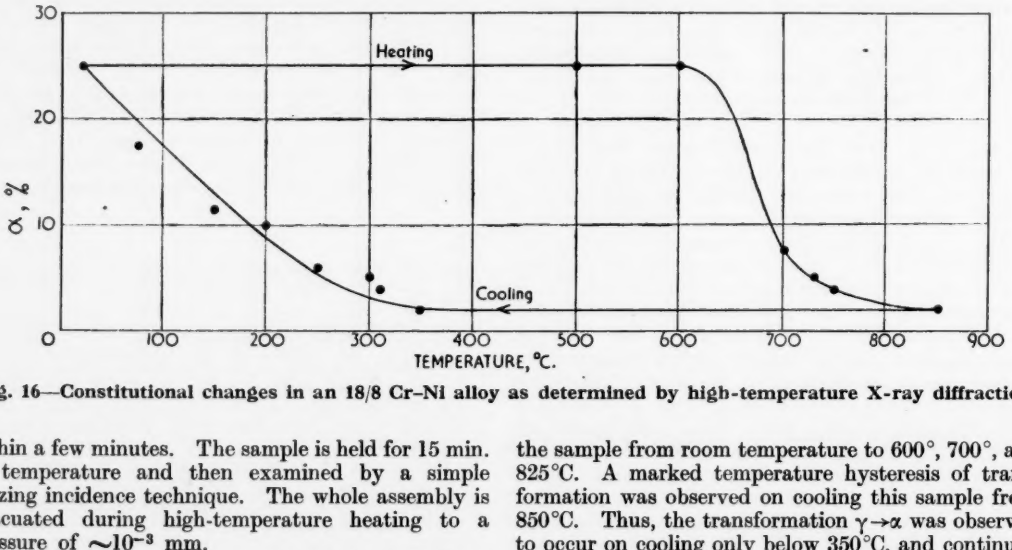


Fig. 16—Constitutional changes in an 18/8 Cr–Ni alloy as determined by high-temperature X-ray diffraction

the sample from room temperature to 600°, 700°, and 825°C. A marked temperature hysteresis of transformation was observed on cooling this sample from 850°C. Thus, the transformation γ→α was observed to occur on cooling only below 350°C. and continued progressively with decreasing temperature until on reaching room temperature the original 25% α had reappeared. Holding periods of 5 min. to 64 hr. after reaching room temperature had no effect on the amount of α detected in this sample. Figures 6*e–j* show the increase in the relative intensity of the ferrite diffraction line observed on cooling below 350°C. to 300°, 200°, 75°, and 23°C. It is concluded from the above that since no γ→α transformation was found to occur on cooling from 850° to 350°C., the α phase observed after tempering at 700°C. could not have formed at this temperature but only on subsequent cooling to temperatures below 350°C. These low temperatures (below 350°C.) are in keeping with a martensitic mode of transformation γ→α and confirm the conclusions reached in the present paper and in other publications.

Effect of the Composition of Gas-Turbine Alloys on Resistance to Scaling and to Vanadium Pentoxide Attack

By G. T. Harris, M.A., F.Inst.P., F.I.M., H. C. Child, B.Sc., A.I.M., and J. A. Kerr, B.Met.

SYNOPSIS

The scale resistance in moving air of some typical gas-turbine alloys with and without coatings of vanadium pentoxide has been studied throughout their useful temperature range. The duration of the tests has been up to 1120 hr. in 70-hr. cycles. In all cases vanadium pentoxide coatings have a deleterious effect, which is most pronounced for iron-base alloys, and at temperatures above 750° C.

A systematic study has also been made of the effect of the base composition (iron, cobalt, nickel, and chromium) and of added strengthening elements (molybdenum, tungsten, niobium, vanadium, and titanium) on the scale resistance with and without vanadium pentoxide coatings. General conclusions have been drawn about the composition requirements if the maximum resistance to vanadium pentoxide attainable with austenitic materials is to be achieved.

Molybdenum additions have been shown to be permissible to materials containing 30% of iron, or less, without causing undue scaling at 950° C. in still or moving air. The drastic effect of still air on iron-base compositions containing molybdenum and vanadium has been confirmed. 1008

Introduction

In recent years many new alloys based on Fe, Ni, Co, and Cr, with additions of Mo, W, Nb, V, and Ti, have been developed for use as high-temperature components in gas turbines. The criterion of development has been creep strength, and for most applications in gas turbines for aircraft use the scale resistance of these alloys proved to be quite satisfactory, owing to the use of suitably chosen base compositions, generally containing chromium, as had been shown desirable in such early contributions as that by Hatfield[1] in 1938.

The effect of large additions of such elements as Mo, W, Nb, and V on the scale resistance of these alloys was, however, but little known, and Leslie and Fontana[2] showed, for example, how under some conditions, particularly in still air, additions of molybdenum could be detrimental. As the corrosive conditions in service became more severe, *e.g.*, when residual oils were considered as a fuel for gas turbines, the problems of scale resistance were further emphasized.

Amongst the first to appreciate the difficulty of using residual oils were Schläpfer, Amgwerd, and Preis,[3] who found that any oil ash containing vanadium markedly accelerated the scaling of heat-resistant steels, and that the alkali content of the ash also influenced the extent of the attack. So severe is this attack that gas turbines run on residual oil are not a practical proposition unless the blade temperatures are less than 550° C., until such time as improved materials or engineering design can overcome the problem. A solution may also be found in the use of additives to the oil, which will combine with the vanadium pentoxide of the ash and render it chemically inert.

The present investigation had, accordingly, two main aims:

(i) The determination of the scale resistance of typical commercial gas-turbine alloys, with and without vanadium pentoxide coatings, over a wide temperature range

(ii) A systematic study of the effect of the composition of austenitic Ni–Co–Cr–Fe alloys on the scale resistance, with and without vanadium pentoxide coatings.

The creep strength of most of the alloys used for the systematic study of the effect of composition on scale resistance had already been studied[4] in the course of developing a rotor-blade alloy.

For convenience the report is divided into four parts:

(1) The scale resistance in moving air of some typical gas-turbine alloys with and without a coating of vanadium pentoxide

(2) A study of the effect on the scale resistance in moving air of Mo, W, Nb, Ti, and V additions to a given base

(3) A study of the effect on the scale resistance in moving air of the base composition

(4) A study of the effect of still air on the scale resistance of a selection of the alloys.

EXPERIMENTAL PROCEDURE

The scaling specimens are cylindrical, 0·875 in. long × 0·45 in. dia., and have a ground finish all

Manuscript received 16th June, 1954.

Mr. Child and Mr. Kerr are in the Research Department of William Jessop and Sons, Ltd., of which Mr. Harris is Director.

Table I
CHEMICAL ANALYSES OF TYPICAL GAS-TURBINE ALLOYS

Alloy	C, %	Si, %	Ni, %	Co, %	Cr, %	W, %	Mo, %	V, %	Nb, %	Ta, %
H.31	0·38	0·3	...	...	1·10	...	0·75	...	...	...
H.40	0·22	0·4	0·3	...	2·7	0·5	0·5	0·75	...	...
H.46	0·15	0·4	...	...	11·5	...	0·45	0·3	0·25	...
G.18*B*	0·4	1·0	13	10	13	2·5	1·8	...	3·0	...
G.19	0·4	1·0	13	10	20	2·5	1·8	...	3·0	...
G.32	0·3	0·3	12	45	19	...	2·0	2·8	1·2	...
G.34	0·8	0·3	12	45	19	...	2·0	2·8	1·2	...
G.39	0·6	1·0	65	...	20	3·0	3·0	...	1·5	1·5
R.20	0·1	0·3	14	...	19	...	...	...	1·7	...
R.22	0·3	1·4	14	...	25	3·0	...	...	...	...
R.23	0·12	1·8	22	...	25	...	...	...	...	...

over. A multi-tube resistance-heated furnace is used, three or four small-diameter tubes being placed inside the larger wire-wound tube, which is 18 in. long. Each of the smaller tubes can hold up to six scaling specimens, which are generally placed in a refractory boat. The furnaces are wound in three zones, which allows the temperature gradient along the specimen tubes to be controlled. The furnace temperature is maintained constant by an electronic controller of the Prosser type.

The separation of the specimens into different inner tubes means that the attack of various metal oxides can be investigated for several specimens of the batch without fear of contamination of the specimens in the adjacent tubes. This is particularly important, for instance, when dealing with steels high in molybdenum, when the volatile oxide of molybdenum is liable to alter the scaling characteristic of the adjacent specimens.

A stream of preheated air containing about 3% of moisture is passed over the specimens, the flow rate being about 10 ft./min. The decision to saturate the air with moisture was taken because it was felt that otherwise the variation in humidity might lead to significant differences. This procedure was felt to be preferable to drying the air, as engine atmospheres normally contain large amounts of water vapour.

The preheating is carried out by passing the air through a narrow-bore silica tube, which stretches nearly the full length of the furnace and is then bent at 180° back into the tube carrying the specimens.

Where tests are of short duration, a single 24- or 70-hr. cycle has been used. For longer-duration tests, four of the 70-hr. cycles totalling 280 hr., or 16 totalling 1120 hr. have been used. After each cycle the specimen is cooled to room temperature,

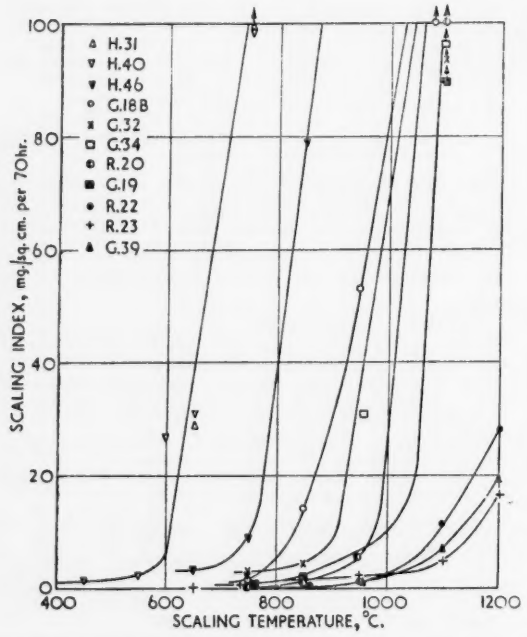


Fig. 1—Effect of temperature on scale resistance of some typical gas-turbine alloys

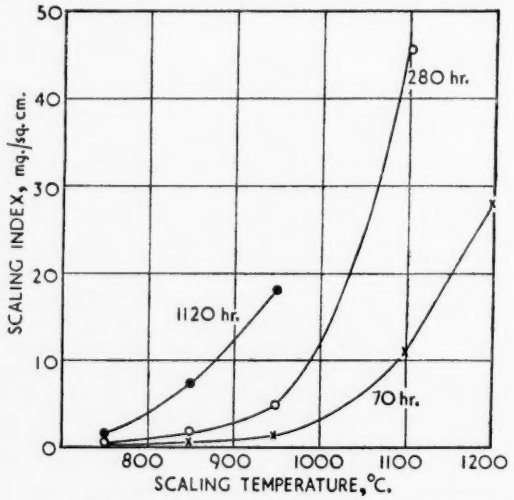


Fig. 2—Effect of time and temperature on scale resistance of R.22

Table II

RESISTANCE TO SCALING IN MOVING AIR

Scaling indices in mg./sq. cm.

Quality	Temperature, °C. :	550	650	750	850	950	1100	1200
H.31	70 hr.	3·6	59	122	177			
	280 „	7·8	122	379	596			
	1120 „	19·1						
H.40	70 „	3·8	18·1	100	234			
	280 „	5·9	33·1	260				
	1120 „	13·4						
H.46	70 „	1·9	3·0	2·4	79			
	280 „	1·8	6·3	7·5	135			
	1120 „	4·7	9·7	12·2				
G.18*B*	70 „			0·9	14·2	52	388	
	280 „			1·1	45	92		
	1120 „			2·4	117			
G.19	70 „			0·47	2·3	9·5	109	*C*
	280 „			0·56	4·1	16·9	*C* (3rd cycle)	
	1120 „			1·1	6·0	142·3		
G.32	70 „			1·2	4·1	42	376	
	280 „			2·2	7·0	103		
	1120 „			5·6	9·7			
G.34	70 „			2·0	3·7	30·5	970	
	280 „			3·1	6·1	123		
	1120 „			4·5	12			
G.39	70 „					1·0	7·0	19·6
	280 „					2·3	16·3	66·3
	1120 „				3·0	6·0	162	
R.20	70 „			0·35	1·0	5·2	638	
	280 „			0·44	1·75	56·3	*C* (3rd cycle)	
	1120 „			1·3	4·2			
R.22	70 „				1·0	2·5	11·3	28
	280 „				1·6	4·8	50	
	1120 „			1·3	7·3	18·4	255	
R.23	70 „				1·2	2·5	4·5	17
	280 „				1·2	4·6	42	59
	1120 „			1·0	5·2	11·8	129	

C indicates that the specimen has almost completely scaled away

any loose scale is removed, and the next cycle is begun.

After experiments with various acid and molten salt reagents, a 2% sodium hydride solution in molten caustic soda at about 360° C. was found to be most suitable for descaling purposes. After treatment for about 1 min. in the bath, followed by a quench in water, the scale is transformed to a metal powder which can be removed by means of an india-rubber. The metal loss is normally zero and rarely more than 0·2 mg./sq. cm.

Where vanadium pentoxide coatings are to be used, a suspension of the oxide in benzene is painted on the specimen, the weight of coating after evaporation of the benzene being controlled at 1·4–1·6 mg./sq. cm.

The scaling index of a given specimen has been defined as the weight loss in mg./sq. cm. The time associated with such a scaling index is always quoted.

Table III

TEMPERATURE TO GIVE AN AVERAGE SCALING RATE OF 1 mg./sq.cm. hr. WITH AND WITHOUT VANADIUM PENTOXIDE COATINGS

Alloy	Without Vanadium Pentoxide (70-hr. Test)	With Vanadium Pentoxide (24-hr. Test)
H.40	720° C.	640° C.
H.46	840° C.	780° C.
G.18*B*	960° C.	810° C.
G.19	1090° C.	810° C.
G.32	980° C.	980° C. (approx.)
G.39	1250° C.	1120° C.
R.20	990° C.	830° C.
R.23	1250° C.	840° C.

DISCUSSION OF RESULTS

Part 1

The chemical analyses of the gas-turbine alloys investigated are given in Table I.

The scale resistance in moving air of these materials in the temperature range 400–1200° C. is compared in Fig. 1, using the 70-hr. scaling

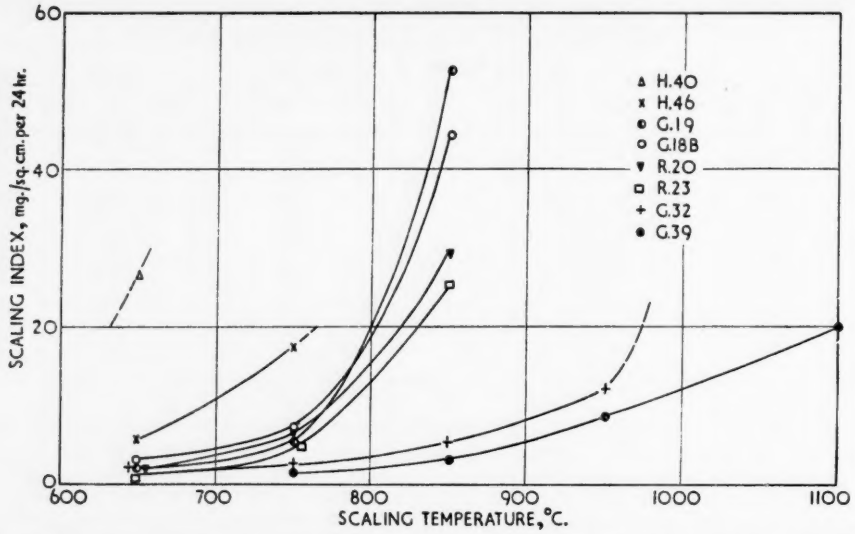


Fig. 3—Effect of temperature on resistance to vanadium attack of some typical gas-turbine alloys in moving air

index as the criterion. For all the alloys studied there is a pronounced increase in scaling attack at some well defined temperature, ranging from just over 600° C. for alloys H.31 and H.40 to over 1200° C. for G.39 and R.23.

For tests of longer duration this characteristic temperature is, as would be expected, somewhat lower, as shown in Fig. 2 for R.22. The results of tests of durations of up to 1120 hr. for the other alloys investigated are recorded in Table II.

The scale resistance of a selection of the alloys coated with vanadium pentoxide has been determined, the test duration in this case being only 24 hr. Figure 3 shows the variation in scale resistance with temperature for these conditions. For most of the alloys studied there is a pronounced increase in the scaling attack at about 770° C. Table III compares the temperature to give a scaling rate of 1 mg./sq.cm. hr. with and without vanadium pentoxide coatings, and these results illustrate some interesting points:

(i) The steels of relatively low scale resistance in air are not markedly affected by the vanadium

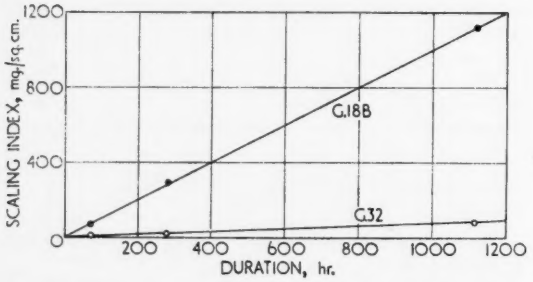


Fig. 4—Effect of time on resistance of G.18*B* and G.32 to vanadium pentoxide attack at 850° C. in moving air

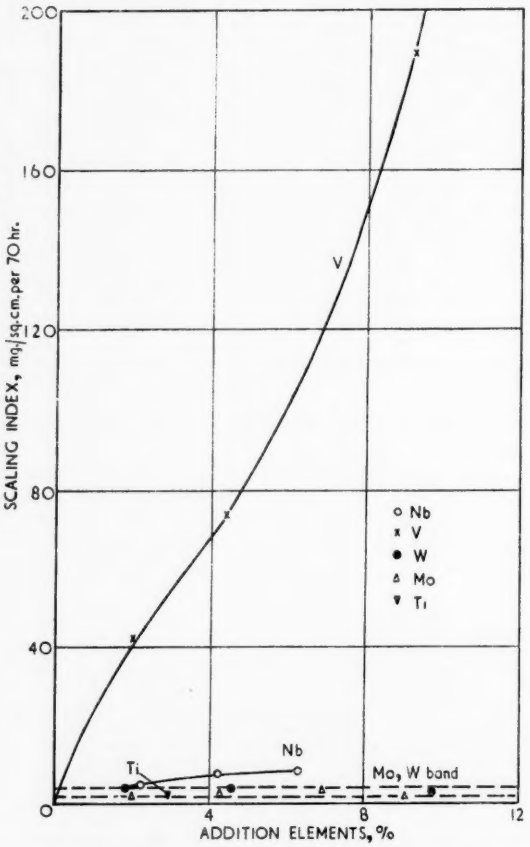


Fig. 5—Effect of addition elements on scale resistance of 20% Ni, 20% Cr, 20% Co, 0·5% C alloys at 950° C.

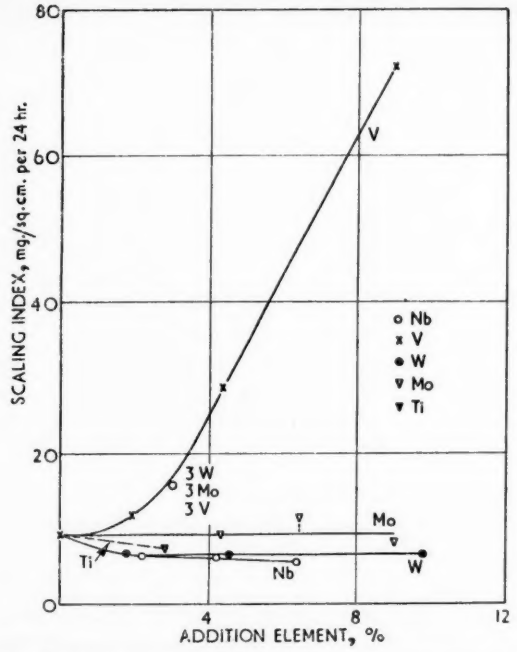


Fig. 6—Effect of addition elements on resistance to vanadium pentoxide of 20% Ni, 20% Co, 20% Cr, 0·5% C alloys at 850° C.

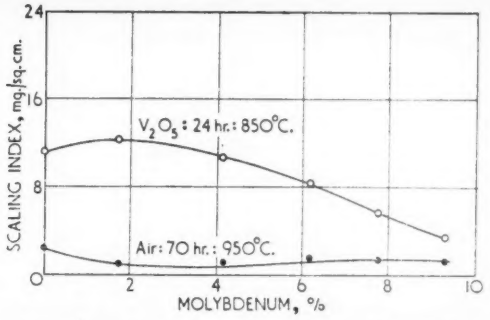


Fig. 7—Effect of molybdenum additions on scale resistance of a low-carbon, 20% Ni, 20% Co, 20% Cr alloy

pentoxide coating, owing to their low service temperature

(ii) The higher chromium level of alloy G.19 compared with G.18*B* has resulted in a marked improvement in the resistance to scaling in air, but both alloys scale equally severely with a vanadium pentoxide coating

(iii) The simple austenitic alloys (R.20 and R.23), although slightly superior to G.18*B* when coated with vanadium pentoxide, have suffered a greater reduction in scale resistance due to the coating than has this alloy.

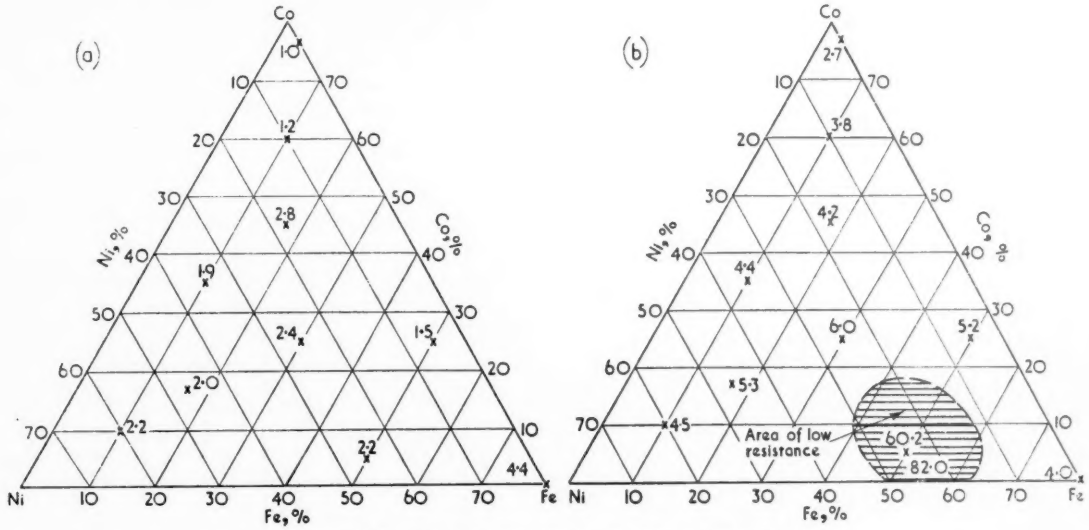
(iv) The vanadium pentoxide coating has little effect on alloy G.32, which is attributed to the fact that this alloy contains nearly 3% of vanadium as an alloying element and consequently always has vanadium pentoxide present in the scale

(v) The nickel-base alloy G.39 is the most resistant to vanadium pentoxide attack.

Figure 4 shows how both G.32 and G.18*B* scale at a linear rate at 850° C. when coated with vanadium pentoxide, the coating being renewed at the end of each 70-hr. cycle.

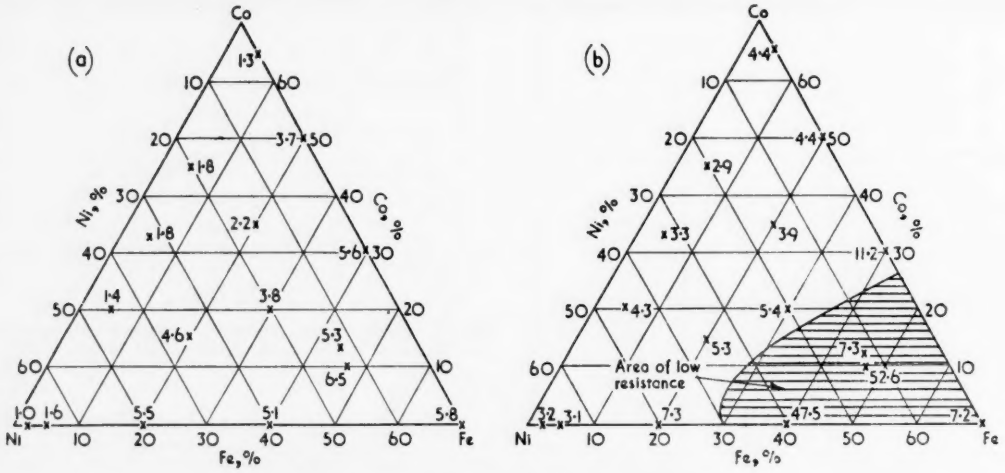
Part 2

The effect of various addition elements on the scale resistance at 950° C. in moving air of a 20% Ni,



Scaling indices: (*a*) mg./sq. cm. per 70 hr.; (*b*) mg./sq. cm. per 24 hr.

Fig. 8—Effect of base composition of 20% Cr alloys on (*a*) scale resistance at 950° C., (*b*) resistance to V_2O_5 at 850° C.



Scaling indices: (*a*) mg./sq. cm. per 70 hr.: (*b*) mg./sq. cm. per 24 hr.

Fig. 9—Effect of base composition of 3% W, 3% Mo, 3% Nb, 20% Cr alloys on (*a*) scale resistance at 950° C., (*b*) resistance to V_2O_5 at 850° C.

20% Co, 20% Cr, 0·5% C, Fe-base alloy is shown in Fig. 5. The only addition element to cause a decrease in scale resistance is vanadium. Vanadium as an alloying element will, of course, give rise to vanadium pentoxide in the scale. High molybdenum additions are quite satisfactory in a base of the type studied. Figure 6 shows that the same conclusions hold when a vanadium pentoxide coating is applied, the scaling temperature being 850° C. The fact that large molybdenum additions are not deleterious is again attributed to the alloy base used, and evidence to confirm this is given in Part 3 of the investigation. The effect of molybdenum additions on the scale resistance of low-carbon, 20% Ni, 20% Co, 20% Cr alloy, with and without vanadium pentoxide coatings, is shown in Fig. 7. Once again molybdenum additions are not deleterious.

As the opinion is widely held that molybdenum is deleterious to scale resistance, the point requires stressing that the evidence for this has come mainly from 18/8-type austenitic materials or from less highly alloyed materials than the 20% Ni, 20% Co alloys studied here. Preece and Lucas[5] found that with Ni–Mo alloys, molybdenum additions of up to 15% caused only a slight loss in scale resistance at temperatures of up to 1200° C., whilst for Co–Mo alloys molybdenum actually improved the scale resistance.

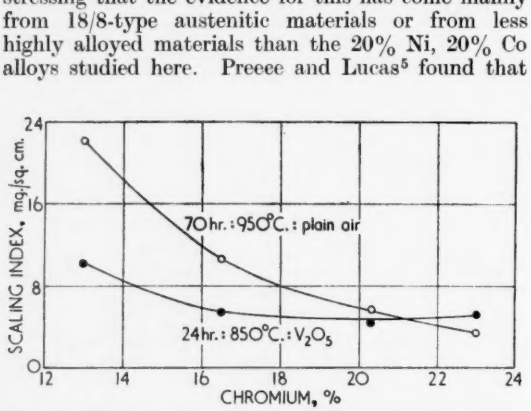


Fig. 10—Effect of chromium on scale resistance of 20% Ni, 20% Co, 3% W, 3% Mo, 3% Nb, 0·5% C alloy

Part 3

The influence of the Ni : Co : Fe ratio of the base composition of 20% Cr alloys with no other carbide-forming additions is shown in Figs. 8*a* and *b*. In air at 950° C. there is little change of scaling index across the composition field. With a vanadium pentoxide coating, however, there is one small area of low resistance at about 25% Ni, 55% Fe. The extent of this field has not been established, but repeated experiments have confirmed its existence. This is in line with the work of Graham, Lewis, and Taylor,[6] who find that 20% Cr alloys containing 31% and 37% Ni are less resistant to oil ash containing vanadium pentoxide than 18% Cr, 8% Ni, and 20% Cr, 80% Ni materials.

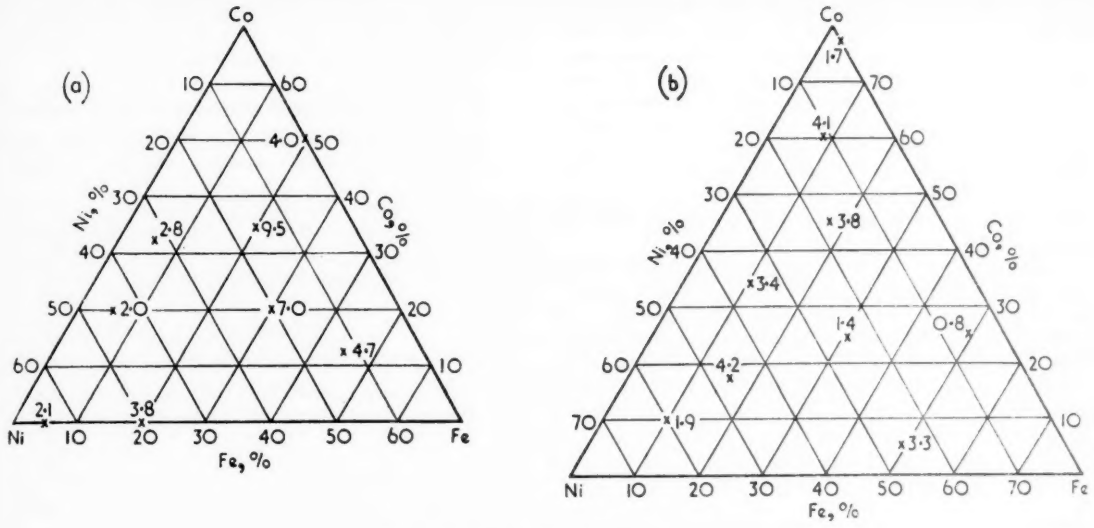
Figures 9*a* and *b* illustrate the same effect for alloys

Table IV

EFFECT OF ATMOSPHERIC CONDITIONS ON SCALING

0·5% C, 20% Ni, 20% Cr, 20% Co alloy containing additions of various carbide-forming elements

Carbide Former, %	Scaling Index per 70 hr. at 950° C. Moving Air	Still Air
None	2	3·3
2·0% V	41·8	44·5
4·4% V	63·6	77·4
9·0% V	192	466·5
2·2% Nb	4·4	2·2
4·2% Nb	7·6	4·4
6·4% Nb	8·1	20·6
1·9% W	3·5	3·1
4·5% W	5·3	4·4
9·7% W	2·7	3·7
2·9% Ti	5·0	2·7



Scaling Index: mg./sq. cm. per 70 hr.

Fig. 11—Scale resistance in still air at 950° C. of (*a*) 3% W, 3% Mo, 3% Nb, 20% Cr alloys; (*b*) Ni–Co–Fe alloys with 20% Cr

containing other carbide-forming elements, *viz.*, 3% of tungsten, 3% of molybdenum, and 3 %of niobium. In this case the area of low resistance is greater, including all alloys containing more than 40% Fe. The 20% Ni, 20% Co alloy lies in the field of better resistance and confirms the conclusions drawn earlier that the resistance of high-molybdenum alloys could, in that case, be attributed to the alloy base.

Figure 10 shows that the effect of chromium under such conditions is to improve the resistance to scaling in air in the expected manner. With a vanadium pentoxide coating present, the improvement due to chromium over the range studied is much less marked.

Part 4

As several investigators, including Leslie and Fontana,[2] have shown that molybdenum-containing steels are much more susceptible to attack by scaling in a static than in a moving atmosphere, it was deemed advisable to study some of the alloys under static conditions.

Table IV compares the scaling index at 950° C. for 70 hr. in moving and still air of the vanadium, niobium, tungsten, and titanium alloys, and Table V gives the results for the molybdenum series. For those alloys containing 20% Ni, 20% Co, 20% Cr, still air has little or no deleterious effect.

Figures 11*a* and *b* show the scale resistance in still air of the Ni–Co–Fe series with and without carbide-forming additions. Comparison with Figs. 9*a* and 8*a* again shows that still air has had little effect.

As no tests were carried out on high-iron alloys, the series of alloys whose results are shown in Table VI was studied, the alloys containing 2·6% of molybdenum and 1·3% of vanadium. A very large increase in scaling occurred in still air.

Table V

EFFECT OF DIFFERENT ATMOSPHERIC CONDITIONS ON SCALING

0·05% C, 20% Ni, 20% Co, 20% Cr alloy with molybdenum additions

Mo, %	Scaling Index per 70 hr. at 950° C.		Scaling Index per 24 hr. at 850° C., Vanadium Pentoxide Coating	
	Moving Air	Still Air	Moving Air	Still Air
0	2·2	3·9	11·2	4·8
1·7	1·5	3·6	12·1	6·7
4·1	1·3	1·6	10·5	7·2
6·1	1·1	5·1	8·3	7·2
7·7	1·5	2·6	6·6	5·5
9·3	1·3	3·3	3·6	...

CONCLUSIONS

The scaling index of all the typical gas-turbine alloys studied increases markedly over a narrow temperature range depending on the alloy and the duration of the test, and hence the scaling indices determined from 70 to 1120 hr. enable the useful service temperatures in air to be assessed.

The effect of vanadium pentoxide coatings is to lower markedly the useful service temperature, notable exceptions being alloys rich in vanadium, which always have vanadium pentoxide present in the scale. The scaling rate, if the vanadium pentoxide coatings are renewed every 70 hr., is constant with time.

Table VI

EFFECT OF MOVING AND STILL AIR ON SCALE RESISTANCE OF IRON-BASE ALLOY

Basic Composition : C 0·15% Ni 12% Mn 0·8% Mo 2·6% Si 0·5% W 1·3% V 1·3%

Cr, %	Scaling Index per 70 hr. at 950° C.	
	Moving Air	Still Air
16	44	>900
18	46	>900
20	32	>900
22	8	>900

The most important conclusion of the investigation is that for alloy bases rich in nickel, cobalt, and chromium, additions of molybdenum, tungsten, niobium, and titanium have no pronounced deleterious effect on scale resistance at 950° C. in moving or still air. The addition of vanadium to such bases does, however, lower the scale resistance markedly. The effect of still air on the scale resistance can be pronounced in the case of iron-base alloys containing molybdenum and vanadium, as has been shown by other workers.

Although none of the alloys investigated has a satisfactory resistance to vanadium pentoxide attack, some are much more resistant than others. In general the resistance is a function of the base composition, *i.e.*, the Ni : Co : Fe ratio. If the iron content of the alloy is less than 30%, the alloy will probably be reasonably resistant to vanadium pentoxide attack, provided that:

(i) The chromium content is at least 16%
(ii) The vanadium content of the alloy does not exceed 2%.

Whilst comparable resistance can be attained with higher iron contents, the other conditions are much more stringent and have been less fully studied in the present investigation. It is considered, however, from the present investigation and from other experience, that the following conditions will approximate where the iron content is greater than 30%:

(i) The chromium content shall be at least 16%
(ii) The nickel content shall not lie in the range 10–40%
(iii) The vanadium content shall be less than 0·5%
(iv) The molybdenum content shall be less than 3%.

These conclusions, it should be stressed, are of an approximate nature. Many service conditions will preclude the use of alloys containing more than 30% of iron owing to strength criteria.

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LETTER TO THE EDITOR

Iron-Oxide Deposition in Open-Hearth Furnaces

In recent studies on the cause of excessive wear at particular points on open-hearth furnace roofs use has been made of a technique suggested some three years ago by J. H. Chesters. The method, which is extremely simple, consists of inserting a series of sintered alumina thermocouple sheaths of $\frac{3}{8}$-in. dia. through $\frac{1}{2}$-in. holes in selected roof bricks. Within a few minutes such probes become stained with iron oxide and where conditions are bad may even be completely penetrated (*see* Fig. 1). Quantitative values for the rate of arrival of iron oxide can be obtained by cutting off a measured length of the probe tip and analysing for total iron. With a new roof a fixed distance of penetration beyond the inner face—usually 1–2 in.—is employed.

During a recent trial the following information was obtained:

(i) The rate of wear at selected points on the roof—assessed by determining at various stages in the campaign the change in length of standard probe covered by deposit
(ii) Rates of deposition at different stages during a heat, *e.g.*, before and after hot-metal addition
(iii) Comparative deposition rates at different points on the roof, which vary by as much as 20 : 1
(iv) The direction of gas flow, as indicated by the side of the probe showing maximum discoloration or attack.

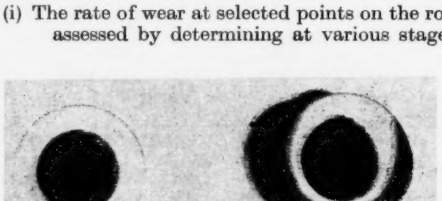

Fig. 1—Condition of test probes after 20 min. exposure in furnace : (*left*) incoming end, (*right*) outgoing end of furnace

The results of this trial and of others carried out since on cold-charged furnaces are most encouraging, in that there appears to be a close correlation between the rate of arrival of iron oxide at a given point and the observed rate of roof wear during a campaign. Incidentally it was noted that at the central point in the roof deposition was heaviest on the side furthest from the active burner, confirming indications from flow-pattern models of reverse flow beneath the roof.

This flux-probe technique, used in conjunction with temperature and gas-composition measurements made through the same holes, should prove invaluable in linking flow-pattern and mixing studies on models with operating conditions in actual furnaces.

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25th January, 1955

Correspondence on the Paper—

SUB-CRITICAL DECOMPOSITION OF CARBIDE PHASE IN SOME LOW-CARBON SILICON STEELS*

By E. D. Harry

Mr. **A. D. Hopkins** and Dr. **K. Sachs** (G.K.N. Group Research Laboratory) wrote: We have read Mr. Harry's paper with great interest and feel that his explanation of the mechanism of graphitization may be expanded in the following way. Hitherto it seems to have been tacitly assumed that the presence of silicon causes iron-silicon carbide to form, which is less stable than pure cementite, but recent work by Bunin† has suggested a more precise mechanism for graphitization. His theory is based on the observation that if a concentration gradient can be produced in silicon ferrite, pores are formed in which graphite can be deposited.

In his present paper the author has confirmed that oxygen promotes graphitization and that neutral or reducing atmospheres have the reverse effect. To ascribe the effect of increased graphitization to the presence of particles of silica is not a complete explanation, but his suggestion that the silica particle must be in the process of formation in order to be an effective graphitization nucleus seems to afford the basis for fuller explanation. We would suggest that internal oxidation not only produces silica particles but also an area surrounding the growing particle deficient in silicon which will promote diffusion and the formation of micropores. The tendency for carbon to diffuse to regions deficient in silicon has been previously observed by Mr. Harry‡ and we have confirmed this effect in unpublished experiments. The striking effect of cold work again may be explained by the generation of dislocations which accelerate diffusion and the formation of micropores. Such a theory implies that any element that does not normally form a stable carbide will promote graphitization unless some physical mechanism operates to prevent the formation of diffusion micropores or the nucleation of graphite therein.

The effect of aluminium is more complex. When it is absent nitrogen, having diffusion characteristics similar to carbon, can accumulate in the pores and reduce the number of potential sites for carbon agglomeration. The formation of aluminium nitride in the presence of aluminium will prevent the poisoning of the potential nuclei and the uncombined aluminium can then promote graphitization by an oxidation-diffusion gradient mechanism in a similar way to silicon.

Turning to the matters of experimental technique, we would welcome further details of the author's method for determining the amount of graphitization and enquire whether he attempted to make a quantitative estimate of the graphite content or whether qualitative metallographic examination alone was used.

AUTHOR'S REPLY

Mr. **E. D. Harry** (Steel Company of Wales Ltd.) wrote: The application of the theory of Bunin to the phenomenon of subcritical graphitization of carbide provides a neat explanation of a number of the factors involved. However, it will be a rather difficult matter to provide direct experimental evidence to support the hypothesis. Experimental evidence leads to the conclusion that some form of internal oxidation does occur at 600° C. but even this will be difficult to prove directly.

With regard to the effect of cold-deformation, the acceleration of diffusion caused by the cold-work is, of course, a factor and it may also be that the effect, reported by Cottrell§¶ on the interaction of edge dislocations and carbon atoms, may have to be considered. According to Cottrell's results the energy binding a carbon atom to a dislocation is greater than that binding it as an iron-carbide particle. It has also been shown that the application of cold-work accelerates the 'precipitation' of carbon from solid solution, as measured by internal friction. The fact that a carbon atom was bound to a dislocation would, of course, render it ineffective as far as internal-friction effects are concerned.

That nitrogen will diffuse to the micropores which act as graphitization nuclei and poison them is quite probable. Some interesting results would probably result from an investigation of the effect of nitrogen on the graphitization of silicon steels.

The precise mechanism involved in the subcritical decomposition of carbide still remains to be completely understood.

With regard to the experimental technique, no attempt was made to obtain a quantitative estimate of the amount of graphite either by chemical or metallographic counting methods. Graphitization was taken to be complete when no free cementite could be observed at a magnification of × 950 using an oil-immersion lens.

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* *J. Iron Steel Inst.*, 1954, vol. 178, Oct., pp. 109–112.

† K. P. Bunin, *Doklady Akad. Nauk S.S.S.R.*, 1954, vol. 15, pp. 97–100.

‡ E. D. Harry, *J. Iron Steel Inst.*, 1951, vol. 167, pp. 241–246.

§ A. H. Cottrell, "Dislocations and Plastic Flow in Crystals," pp. 133–150: 1953, Oxford, Clarendon Press.

¶ A. H. Cottrell and G. M. Leak, *J. Iron Steel Inst.*, 1952, vol. 172, pp. 301–306.

Dependence of Mechanical Properties of Forgings on Local Strain

By P. M. Cook, B.Sc., A.Inst.P., A.I.M.

SYNOPSIS

Previously reported Plasticine model experiments have shown that tool width and reduction have an important effect on the distribution of strain within forged material. The aim of the present experiments was to determine whether large internal strain variations give rise to variations of any consequence in the mechanical properties of forged steel ingots.

Two small 0·6% carbon steel ingots were slabbed down, one in four passes using narrow 'bites' (to produce uniform internal deformation) and the other in two passes using wide 'bites' (to produce very uneven internal deformation).

Tensile tests taken after normalizing, at selected positions within both slabs, revealed substantially uniform ductility throughout the one which was evenly strained, and appreciable variation in the other. In the latter case ductility was highest in the most heavily deformed regions. 1067

It has long been appreciated that the mechanical properties of a forging are influenced by the amount of hot working or forging reduction from the ingot, and a great deal of literature is available on this subject. Of particular interest is the extensive and systematic study of the effect of forging reduction on the mechanical properties of an S.A.E. 1045 steel by Grobe, Wells, and Mehl.* In this and in previous work, appreciable scatter is evident in test results obtained from specimens taken from material which has received similar forging reduction. Such scatter, which makes interpretation of results difficult, is undoubtedly due in part to the heterogeneous nature of the ingot, the uneven distribution of inclusions, slight variations in heat-treating procedure, etc. Attention is now drawn to another serious disturbing factor which so far has apparently not been considered, *i.e.*, the possible variations in local strain within material forged to a constant overall reduction.

In an earlier paper† the use of Plasticine models to study the internal deformations caused by various forging processes has been described. It was shown that for a specific reduction in section, the local strains along the length of a slab or bloom may vary between wide limits or be substantially uniform, depending entirely on the choice of tool width and reduction per pass.

If, therefore, in an investigation concerned with mechanical properties, the forging conditions are such as to produce uneven strain distribution, it is quite conceivable that a certain amount of scatter in the results will be observed, due solely to the test specimens being cut from regions which have received different amounts of deformation. If the deformation patterns are sufficiently uneven, it is quite possible to cut a test piece from a forging reduced overall by 4 to 1 which has been deformed less than a test piece taken from a forging reduced overall by 2 to 1.

Uneven deformation as a cause of scatter in mechanical test results is revealed by the following experiments. Two medium-carbon steel ingots from the same cast (analysis: C, 0·62%; Mn, 1·02%; Si, 0·25%; S, 0·012%; P, 0·036%) and tapering from 6 in. square to 5 in. square by 2 ft. long were forged down to 4 in. in one direction only, under a 200-ton hydraulic press. In one case (ingot *A*), this reduction was effected in two passes using 5-in. wide bites, and in the other (ingot *B*), in four passes using 2-in. wide bites. Before forging, the ingots were heated to 1200° C. and soaked for 1 hr. in a gas-fired furnace, the temperature being recorded by means of a sheathed Pt/Pt–Rh thermocouple inserted through the furnace roof. During forging, the temperature of ingot *A* (measured by an optical pyrometer) fell to about 1050° C. and ingot *B*, which took longer to forge, fell to about 950° C.

Two scale-model Plasticine ingots were also forged using bites and reductions per pass geometrically similar to those used in hot-forging the steel ingots. The distribution of compressive strains along the central planes of these forged Plasticine models are shown in Fig. 1, from which it is apparent that the two reductions with wide forging steps gave rise to a very uneven strain distribution compared with that produced by four lighter reductions with narrower forging steps. (The decrease in average strain towards the bottom ends of the forged ingots is due to ingot taper.) It was assumed, on the basis of an earlier comparison between the behaviour of Plasticine and steel at forging temperatures,† that these strain distributions would be very similar to those produced in the steel slabs.

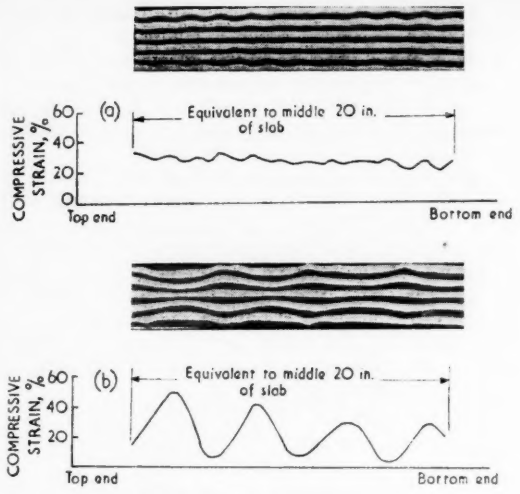
After forging, the steel slabs were normalized from 850° C. and four $\frac{5}{8}$-in. thick slices were cut from each,

* A. H. Grobe, C. Wells, and R. F. Mehl, *Trans. Amer. Soc. Metals*, 1953, vol. 45, pp. 1080–1113.

† P. M. Cook, *Metal Treatment and Drop Forg.*, 1953, vol. 20, Nov., pp. 55–62.

Paper MW/F/50/54 of the Forging Committee of the Mechanical Working Division of the British Iron and Steel Research Association, first received on 30th July, 1954, and in its final form on 2nd December, 1954. The views expressed are the author's, and are not necessarily endorsed by the Committee as a body.

Mr. Cook is Senior Investigator in charge of forging research in the Metal Working Laboratory of B.I.S.R.A. at Sheffield.



(*a*) Slab *B*: 4 ½-in. reductions, 2-in. bites
(*b*) ,, *A*: 2 1-in. ,, 5-in. ,,

Fig. 1—Compressive strain distributions along central planes of slabbed Plasticine ingots

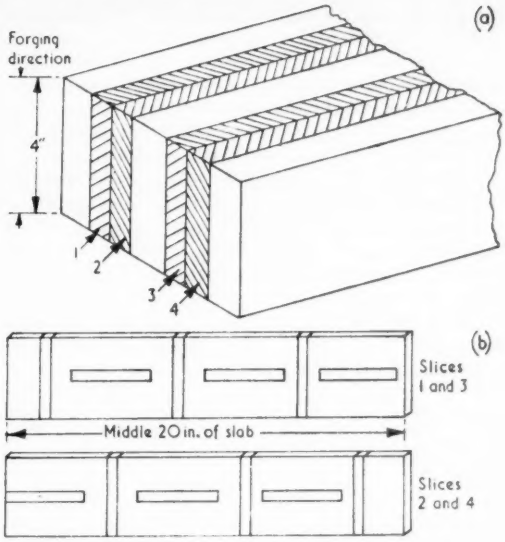


Fig. 2—Details of sampling of steel ingots: (*a*) positions of slices; (*b*) locations of test specimens

as shown in Fig. 2*a*, the centres being discarded to avoid any possible core looseness. Longitudinal and transverse tensile specimens (1·4 in. gauge length × 0·399 in. dia.) were taken from the slices as shown in Fig. 2*b*. These positions were arranged so that in slab *A* the properties were determined as nearly as possible at the maximum and minimum strain values, as indicated by the Plasticine model experiments (compare Figs. 1*b* and 2*b*). From slab *B* 12 test pieces were taken in both longitudinal and transverse directions, all of which had received approximately similar uniform strains of 25–30% (these values and those quoted below were deduced from the Plasticine tests). From slab *A* six test pieces were taken in both directions which had been deformed by about 8%, whilst from the regions of maximum strain (*i.e.*, 50%, 40%, and 30%) only duplicate tests were obtained in each case. The test results are shown in Table I, mean values and standard deviations (in brackets) being quoted for the 8% and 25–30% strains.

Whilst the yield and ultimate tensile strengths are substantially unaffected by strain variations, it is

Table I
TENSILE TEST RESULTS

Slab	Approx. Strain, %	Longitudinal Tests				Transverse Tests			
		Yield Point, tons/sq. in.	U.T.S., tons/sq. in.	Elongation, %	Red. in Area, %	Yield Point, tons/sq. in.	U.T.S., tons/sq. in.	Elongation, %	Red. in Area, %
A	50	23·9	45·1	20·7	36·1	23·1	45·4	10·0	15·9
		24·6	47·0	23·6	44·2	26·7	46·9	18·6	37·2
	40	24·9	41·2	16·4	25·2	24·3	45·9	10·0	12·9
		26·8	45·8	21·4	37·2	25·4	46·1	15·7	23·3
	30	25·6	46·2	15·7	22·7	25·8	41·4	10·7	15·0
		27·1	47·8	16·4	23·2	26·7	46·4	13·6	15·5
	8	26·3	45·9	14·6	21·2	25·6	45·1	10·3	13·9
		(0·8)	(1·3)	(4·1)	(8·0)	(1·4)	(1·8)	(1·1)	(0·7)
B	25–30	25·5	46·6	15·7	20·2	25·2	45·9	12·9	17·2
		(0·5)	(0·6)	(1·8)	(2·2)	(0·5)	(0·7)	(1·0)	(1·1)

apparent that the ductility, as measured by elongation and reduction in area, is variable throughout slab *A*, the higher local strains tending to cause higher ductility. The differences between duplicate tests at the nominal strains of 50% and 40% may be accounted for by the uncertainty in cutting out test pieces exactly at the assumed positions of the maxima on the strain distribution curve. Thus a lateral displacement of 1 in. between the position of a maximum on the curve and the position of the test piece reduces the actual strain to about 30%, at which value the properties differ little from those resulting from 8% strain. In contrast, the values of elongation and reduction in area throughout slab *B* are quite consistent, the scatter being much less than the differences observed in slab *A*.

Although the scope of the present investigation was limited, in that only two medium-carbon steel ingots were examined after a comparatively light reduction, the results confirm that non-uniform local deformation caused by unsuitable forging practice may give rise to local variations in mechanical properties, even though the overall forging reduction is constant.

It is possible that some of the scatter observed in the results obtained by previous workers in this field is due to such variations. It is suggested that in any study of the effect of forging reduction on mechanical properties, particular care should be taken to forge the material with tools and reductions chosen, if necessary by means of Plasticine model experiments, to produce uniform strain distribution. Only under such conditions is a true assessment of the effect of forging reduction possible.

The Supply of Scrap to Open-Hearth Furnaces

By M. D. J. Brisby and W. O. Pendray

SYNOPSIS

This paper discusses problems in the supply of scrap to open-hearth furnaces. Supply systems have been investigated to find out what improvements are desirable and how they can be made. It was found that all melting shops suffer to some extent from charging delays, and recommendations are put forward for improving charging times. 1080

STATEMENT OF PROBLEM

STUDIES of actual charging times show that these vary widely. Table I gives mean values of charging times at six different works. In addition to the variation between mean times exhibited in this Table, there are also wide variations in individual charging times about the mean at each works. This is illustrated by the histograms in Figs. 1*a* and *b* for two of the melting shops included in Table I.

Some degree of variability in charging times within a works is inevitable, but the longer times can be regarded as demonstrating delays in charging beyond some notional standard charging time which is the shortest charging time that can be expected for these furnaces using the required mix of materials (hot metal, cold pig, and scrap).

These delays may be of two basic types:

(i) Delays arising when materials are available at the furnace but cannot be charged at the standard rate because the furnace itself is working sluggishly, and is therefore not in a condition to receive materials at that rate

(ii) Delays arising because materials cannot be made available to the furnace when required owing to failure of the supply system to keep pace with the charging requirements.

The causes and methods of reducing delays in the first category (due to the operation of the furnace itself) will not be considered further in this paper, which is confined to problems related to the supply of materials to the furnaces.

Delays of the second type (due to supply failure) are caused by the interaction of the following independent factors: the demands of the furnaces, the density of the scrap, and the limitations of the supply system (*i.e.*, magnet and charger cranes, charging pans, locomotives, etc., and the effectiveness of their utilization). Delays on this score and the means of reducing them must therefore be considered under three heads:

(i) The demands of the furnaces
(ii) The improvement of scrap
(iii) The improvement of supply services.

THE DEMANDS OF THE FURNACES

Bunching

In all the melting shops examined the supply system was adequate to meet the *average* demand for scrap. In other words, if the melting shop required scrap at a constant rate in tons per hour throughout the day, there would be no charging delays, even with the worst scrap encountered in practice. However, because of the variability of tap-to-tap times, there are occasions when several furnaces require to be charged simultaneously, a state of affairs commonly

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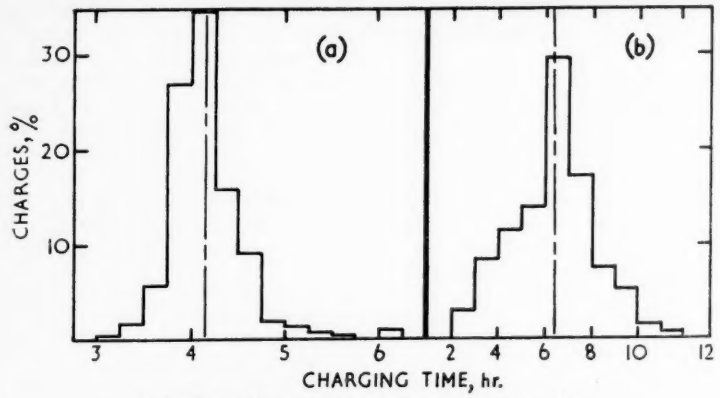
Mr. Brisby is on the staff of the Association's Operational Research Section, and Mr. Pendray, formerly with the Section, is now with the Ford Motor Company, Ltd.



(*a*) Small spread (½-hr. steps); mean charging time 4 hr. 9 min.
(*b*) Large spread (1-hr. steps); mean charging time 6 hr. 18 min.

Fig. 1—Distribution of charging times in two melting shops

known as ' bunching.' In practice, severe bunching almost invariably results in longer charging times. The severity of bunching is determined by the number of furnaces charging together and by the time for which this condition persists.

Figure 2 shows the effect of bunching on actual charging times observed in a cold melting shop operating four furnaces. With two furnaces charging together, the charging times are in the region of 5 hr.; with an occasional third furnace charging, these times creep up to 5½ hr.; and when three furnaces come together for any length of time, charging times are in the region of 6 hr.

Attempts have been made to prevent the bunching of furnaces, but these have usually led to loss of production as, sooner or later, de-bunching involves ' holding back ' furnaces. Recurrent bunched charging must therefore be regarded as inevitable in open-hearth shops, and both scrap and supply services must be capable of coping with it. This is implicitly accepted in the subsequent sections of this paper.

In most melting shops it would not be practicable to provide a supply system which eliminates all bunching delays. This would mean installing sufficient charger and crane capacity, pans, locomotives, etc., to allow *all* furnaces to be charged at the same time, a condition which occurs only at extremely rare intervals. In practice, the cost of further reducing delays must be balanced against the value of the resulting increased output.*

THE IMPROVEMENT OF SCRAP

Scrap Quality and Pan Weights

From the point of view of the melter, good scrap means only two things: scrap free from deleterious materials and scrap which will give a good pan weight.

This paper is concerned with scrap quality as it affects pan weights. The problem of extraneous alloy elements is one which has already been given attention by B.I.S.R.A. and will not be dealt with here.

Scrap grades and prices are fixed by the Iron and

* The theory on which the charging delays are calculated is described in the paper by Solt (*J. Iron Steel Inst.*, 1955, vol. 179, pp. 260–264—this issue). Briefly, the method is as follows. The magnitude of charging delays depends on numerous factors, among which are the charging rate aimed at, the incidence of bunching (which can be calculated on the basis of probability theory), the magnet crane and charger capacities, the range of scrap densities, the number of pans or bogies available for carrying scrap, their turn-round time, and the organization of the shop. If all these factors are known quantitatively, the resulting charging delay can be calculated. If one or more of these factors determining bunching delays are varied and the calculations are repeated, the effect on charging time of adding to the equipment of the shop or of changing its methods of working can be determined.

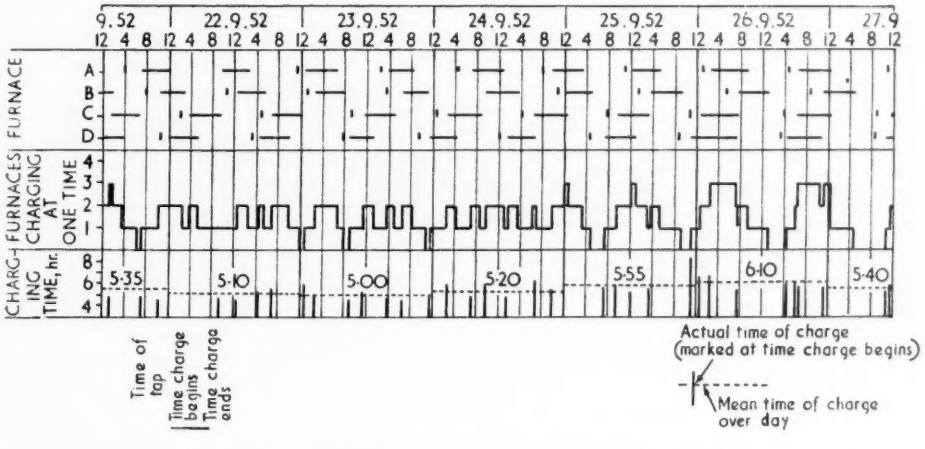


Fig. 2—Charging times of open-hearth furnaces

Table I

CHARGING TIMES OF OPEN-HEARTH FURNACES

Furnace Capacity, tons	Cold Charge, tons	Mean Cold Charging Time, hr.	Mean Cold Charging Rate, tons/hr.
180	110	4	27
180	80	3	27
120	54	2	27
90	50	4¼	13
80	88	4¼	21
60	66	6¼	11

Steel Scrap Order* for fifteen different specifications, but the physical characteristics of scrap are not defined beyond saying that it shall be " in works furnace sizes." Whether a closer specification would help to provide better scrap is a matter of opinion.

Since widely different shapes and sizes of scrap pass by similar names in different works, comparisons between pan weights obtained in different works are largely impossible. In addition, pan weights will also be affected by differences in loading techniques.

Table II illustrates the very wide limits between which pan weights normally vary. Thus, for example, at one works it was found that the pan weights range from 0·3 to 2·7 tons per pan for one type of scrap loaded under similar conditions into identical pans.

A useful way of analysing scrap weights is to plot them in histogram form, as shown in Fig. 3, which gives a distribution of bogie weights for mixed scrap obtained from a sample of 1800 bogies individually weighed (summarized in Table III). The distribution, which shows a marked peak for loads of 1·75 tons per bogie, gives a mean load of 3·28 tons. However, a small proportion of the total tonnage involved (17%) was carried in a large proportion of the bogies used (40%), and more than half the total scrap (57%) was loaded to more than 4 tons per bogie and packed into only 30% of the bogies.

Effect of Bad Scrap

Whilst all melting-shop operators are fully conscious of the nuisance value of bad scrap, nowhere does there appear to be a clear picture of what bad scrap means in terms of delay or loss of production to the furnaces.

At one works where the management were contemplating the installation of a baling press it was necessary to show

(i) The effect of bad scrap on charging delays
(ii) The potential value of better scrap to the shop.

Calculations taking into account the equipment of the shop, its organization, and its scrap quality gave a relationship between mean charging delays and the mean scrap weight per pan, as shown in Fig. 4. (Whilst the shape of this diagram is of general application, the point at which the curve reaches zero delay depends on the conditions obtaining in the works.) This curve is consistent with the supposition that with low pan weights (in this case for charges with average pan weights of 4–6 cwt. per pan) the total charging time is approximately proportional to the number of pans charged. As pan weights increase further, however, the reduction in charging time is no longer proportional but falls off more slowly until, with charges averaging about 11 cwt. per pan, there is no delay due to this cause in this shop.

The lesson to be learnt from this is very clear, namely, that delays due to charging a large number of light pans today will not be made up by charging heavier pans tomorrow. In other words, charging delays will be reduced if the scrap is mixed so that *each* charge has a mean pan weight as close as possible to the overall mean. For example, if over a period the furnaces in the shop are charged with scrap of an average density of 5 cwt. per pan, the average delay per charge would be 100 min.; if later the average scrap density is 9 cwt. per pan, the mean delay suffered by the charges in this subsequent period would be 6 min., giving an overall mean delay of 53 min. If, on the other hand, the scrap had been mixed so that the mean scrap density throughout the two periods had been 7 cwt. per pan, the resultant mean delay would have been reduced to approx. 20 min., an average saving of 33 min. per charge.

Scrap Preparation

Better pan weights can be obtained either by paying more for better scrap or by treating inferior scrap in such a way that more can be packed into each pan. The best course to adopt depends on the relation between the benefit to be gained from higher pan weights and the costs of the alternative ways of achieving them.

The term ' scrap preparation ' is used to indicate that an operation is carried out which modifies the shape or dimensions of individual pieces of scrap. The methods of preparation in current use in the U.K. today are shearing, flame cutting, and pressing.

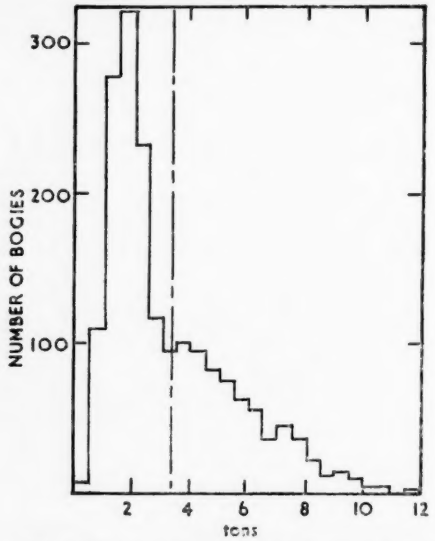


Fig. 3—Distribution of bogie weights for mixed scrap (4 × 30-cu. ft. pans per bogie). Mean load 3·28 tons

* Statutory Instruments 1952, No. 1665, and 1953, No. 170. Supply and Services—Raw Materials (Iron and Steel). The Iron and Steel Scrap Order—1952 (and Amendments Nos. 1, 2, and 3: 1953, 1954). (As the paper was going to press information was received that this Order had been replaced by Statutory Instrument 1953—The Iron and Steel Scrap Order 1954. The remarks in this paragraph are therefore out of date—Ed.)

Table II

SCRAP WEIGHTS PER PAN, tons

Type of Scrap	Approximate Volume of Pans					
	40 cu. ft.		30 cu. ft.		20 cu. ft.	
	Range	Mean	Range	Mean	Range	Mean
Light or mixed bought scrap	0·3–2·7	0·9	0·2–0·6	0·5	0·2–0·9	0·3
Heavy bought scrap	...	...	0·5–1·0	...	0·3–0·8	...
Pressed bundles	0·5–2·2	1·3	...	0·8	0·1–1·1	0·6
Mill scrap	2·3–4·2	3·2	1·2–3·3	1·4	0·4–3·9	1·8

Shearing and Flame Cutting—Many works in the U.K. today have shears and burners, but few make much use of them. They are used chiefly to treat awkward sizes of scrap which could not otherwise be loaded into pans at all, but only rarely as a regular process for raising pan density.

Shearing and flame-cutting costs vary widely from works to works, not only on account of differences in efficiency and organization but also because of differences in the type of scrap treated and in the costing methods used. A representative figure for shearing and flame cutting, including only direct labour and materials but not services and overheads, is 6*s.* per ton. The inclusion of services and overheads will almost double this figure.

Shearing, in contrast to flame cutting, involves the provision of more elaborate handling facilities, since scrap has to be brought to the shears by crane and carefully manhandled into position; burners, on the other hand, can move to the work within a radius of 30–50 ft., so that handling by magnet crane can be done on substantial tonnages at a time and very little manhandling is necessary. Furthermore, flame cutting, unlike shearing, is not subject to any size limitation and is therefore the more practical method of dealing with awkward scrap such as uncoiled wire rope, heavy scrap not in 'furnace sizes,' and internal mill scrap.

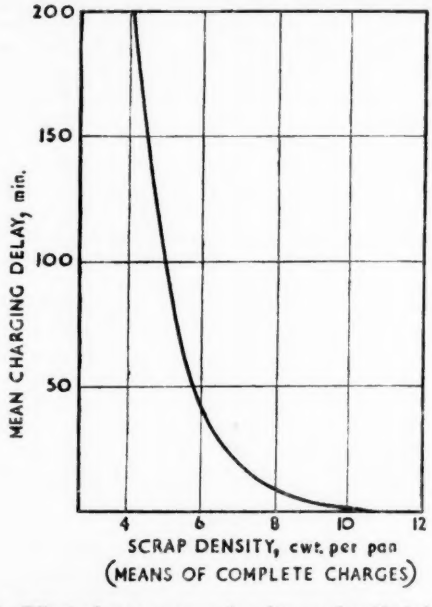


Fig. 4—Effect of mean scrap density on charging delay. This curve, calculated for a particular shop, illustrates the general trend; the actual figures are not generally applicable

Pressing—This is the only satisfactory means of preparing scrap in substantial tonnages and has the advantage of raising the effective bulk density of scrap by a factor of 2–3. This means that pans loaded with press blocks weigh 2–3 times more than when loaded with light scrap. So far as pan weights are concerned this brings press blocks into the category of heavy bought scrap. Steelworks which experience difficulty with their scrap supplies and which have slow charging times think sometimes that their problems would come to an end if they were to install a scrap press. But the problem is to decide what the press is worth in terms of greater output and cost. This will vary from one works to another but the following are the main points at issue:

(i) *Limitation of Scrap Supply*—Although the scrap position in the U.K. today is fairly good, supplies of pressable scrap are scarce, particularly where there are already baling presses in the area. For example, two large presses in the Sheffield area frequently find difficulty in getting supplies to maintain three-shift working

(ii) *Limitation of the Press*—Bought scrap cannot be fed indiscriminately to presses. This is a point which is sometimes not made sufficiently clear by press manufacturers. Although much of what is sold today as Grade 1 scrap (heavy steel scrap) could in fact be charged into strong presses, the occasional heavy section might do considerable damage. With the present grading, only Grades 8 and 11 can be charged safely into presses

(iii) *Costs*—Pressing costs, excluding depreciation and including labour charges, maintenance, and services, range between 7*s.* 6*d.* and 14*s.* per ton. This is for a heavy press with a labour force of 4–5 men. The capital costs of heavy-duty presses range between £30,000 and £45,000, to which must be added £15,000 for foundations, buildings, installation costs, etc. Depreciation on a press may be taken as 6*s.*, 3*s.*, and 2*s.* per ton, depending on whether the press is working

Table III

DISTRIBUTION OF BOGIE WEIGHTS

4 × 30 cu. ft. pans per bogie

Weight per Bogie	Tonnage, %	Bogies Used, %	Mean Weight per Bogie
0–2 tons	17	40	1·40 tons
0–4 „	43	69	2·04 „
More than 4 tons	57	31	6·05 „

one, two, or three shifts per day (assuming a fixed write-off period of 15 years)

(iv) *Output of Press*—The output of a heavy-duty press is 900–1000 tons per week of press blocks (three-shift working)

(v) *Input Limitation of Melting Shop*—Open-hearth furnaces cannot absorb more than about one-third to half of their scrap charge in the form of press blocks, on account of operational difficulties. If, therefore, a works is going to install a press to work a three-shift day, the melting shop must have a scrap consumption of at least 2000–3000 tons of scrap per week. A smaller shop than this could not keep a press fully occupied

(vi) *Price Differential of Scrap*—One of the most important points to watch is the price difference between pressable scrap (Grades 8 and 11) and heavy steel scrap (Grade 1), as after preparation these two scraps give comparable pan weights. The present difference is about £1 per ton.

THE IMPROVEMENT OF SERVICES

Marshalling and Stocking of Scrap

The problem of improving scrap services to the furnaces starts the moment the scrap enters the works. Most works make some attempt to keep different grades of scrap separate in their main stockyards, but few pay enough attention to the marshalling of wagons which are sent to the scrap bay for putting to ground or for direct loading into pans.

Incoming wagons for direct unloading to pans should be set in such a way as to provide a fair mixture of scrap for the crane drivers and to keep long travel on the cranes to a minimum. This will ensure that rakes of bogies will be made up of suitable mixtures of scrap, which, as shown in the previous section, has an important effect on reducing charging delays.

Where scrap is stored on the ground in the scrap shed, such scrap should be segregated by grade and put to ground at specified points.

Loading-Bay Crane Capacity

The rate at which scrap can be loaded into pans has an important bearing on the number of pans and the amount of storage capacity needed. One way to cater for peak periods of furnace charging would be to load pans continuously at a steady rate, independently of what is happening at the furnaces, and build up sufficient stock in pans during slack periods to tide the furnaces over peak periods; at the other extreme, scrap could be loaded more or less as it is wanted. The former requires a large number of pans and storage capacity for them, and the latter requires an excess of crane capacity so that peak loading rates can match peak demands. In fact, some intermediate solution between these two extremes is usually the one that minimizes cost. This is likely to vary from works to works, and should be calculated in each particular case.

The rate at which scrap can be loaded depends on the type of scrap and the layout of the loading bay, as well as on the diameter of the magnet and the general performance of the crane and its driver.

A method frequently used to measure the loading rate of a crane is to conduct a time study of the separate movements of its cycles of operations, recording at the same time the number of lifts to fill one pan and obtaining the weights lifted from weighbridge records. The results of such a study, generally expressed in tons per minute, provide a valuable comparison of the loading characteristics of various types of scrap, but are not a useful measure of the crane's overall performance, since they take no account of the inevitable delays caused when wagons and bogies have to be shunted or replaced, when the crane has to clear the scrap-shed floor of spilt scrap, or when adjacent cranes interfere with each other. Figures for the overall performance of a crane with different types of scrap are best obtained by recording the weights loaded over a period of, say, 30 or 60 min. and expressing the rates in tons per hour, rather than by timing individual movements. Some examples are given in Table IV.

Loading of Scrap

Scrap sheds are traditionally the most untidy places in steelworks and yet good scrap-shed organization and supervision can do much to improve melting-shop efficiency. The principal points where the scrap shed can contribute to the smooth running of the melting shop will now be discussed.

Mechanical Trimming—A really good crane driver can get consistently better pan weights than a bad driver working under the same conditions. He can, within limits, control the scrap lifted, he can drop his load accurately, and he may often be able to trim the scrap in the pan with his magnet so as to compact it and thus make room for another load.

In addition to possessing personal skill, a crane driver needs to work under good conditions to achieve the highest pan weights. His performance will be greatly improved if he can see what he is doing, if his controls are easy to operate, if the crane is fast and easy to manœuvre, and if he has good manual trimmers to co-operate with him.

Manual Trimming—Each magnet crane is usually assisted by two trimmers. Their function is to enable the magnet to load as much scrap into each pan as possible and to ensure that untidily loaded scrap will not fall out of pans during transport or foul the furnace doors during charging.

The suggestion is sometimes made to put more men on trimming, but it is doubtful whether this would make much difference to pan weights. The answer to good trimming lies in teamwork and intelligent co-operation between crane drivers and trimmers, rather than in employing more men.

Fast Loading vs. *High Pan Weights*—When badly loaded pans are sent to the furnace it is often said by way of explanation that it would take too long to load the pans well. It is true that high pan weights can only be obtained at the expense of speed, and a reasonable compromise must be struck. However, too much emphasis is often placed on speed and not enough on weight, especially during periods of peak

Table IV

SCRAP LOADING RATES

Material	Mean Loading Rates, tons/hr.
Press blocks	72
Mill scrap	48
Bought scrap	24
Bought scrap (light)	14

demand. Whilst the balance between speed and pan weight moves somewhat in favour of speed at such times, there can be no doubt that it is bad practice to send half-empty pans to the stage, as has frequently been observed; it is not the pans which are wanted on the stage, but the scrap in them.

The habit of loading pans quickly rather than well tends to persist even when there is no need for speed at all—when furnaces are in fact not calling for scrap. As long as there are no empty pans waiting to be loaded, cranes can always return to improve the weight in pans which would pass for full when the shop is under pressure.

Pre-loading of Pans—Since at almost all works the combined loading capacity of the magnet cranes is insufficient to match the peak demands of the furnaces during bunching, it is essential that the slack periods be used to build up the largest possible stock of pre-loaded scrap (over and above what is needed immediately) in readiness for the next period of bunched charging. This means that empty pans must be removed from the stage for loading as soon as they have been charged and that loading operations must not be allowed to relax when there is no immediate call for scrap. On the contrary, especial care must be taken at these times to obtain the maximum pan weights, since only in this way can the demands of the furnaces be adequately met when bunching next occurs.

Scrap Mixing—In the previous section it was shown that charging delays result if the mean scrap density varies much from one time to another. To prevent such delays the traffic department should never send to the loading bays a shunt of wagons consisting entirely of light or entirely of heavy scrap; they should always send a mixture. At the same time the crane drivers, who should always have wagons with varying scrap densities at their disposal, should never load only heavy or only light scrap for any length of time, but should mix the heavy with the light.* This recommendation implies a higher degree of co-operation between shifts than is customary in many works. It is necessary to overcome the tendency for the outgoing shift to use the best scrap, leaving the new shift to cope as best it can with what is left.

The desirability of improving pan weights by mixing scrap within the pans (*i.e.*, by dropping heavy scrap

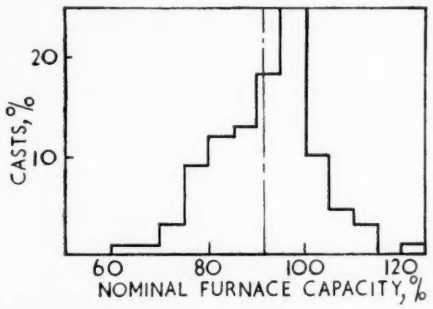


Fig. 5—Distribution of cast weights. Mean cast: 92% of furnace capacity

such as crop ends on top of shearings or other light scrap) is widely appreciated and need not be stressed here.

Emergency Reserve—Over and above the routine pre-loading of scrap in preparation for the demands of the furnaces when they next bunch, it is also good policy to hold a small stock of particularly heavy scrap, preferably mill scrap, for use in emergencies, such as traffic breakdowns or periods of particularly severe bunching and at weekends, when mills may be shut down for four shifts and when, therefore, the average scrap density tends to fall.

The value of heavy scrap lies in the fact that it occupies little bogie or bench space, so that the operation of the system is not interfered with if some is put to storage. Except for the fact that heavy mill scrap is not charged into an empty furnace because it is liable to damage the bottom, there is in general no advantage in charging heavy scrap at any particular time. There are, of course, metallurgical considerations which reserve particular qualities of mill scrap for certain specifications of steel.

Notwithstanding these reservations it should still be possible to set aside a stock of mill scrap. In one eight-furnace shop producing 7500 tons/week, it was suggested that 30 tons of mill scrap should be set aside to cope with bunching during the week and that 60–75 tons of mill scrap should be set aside for the weekend. It was shown that the adoption of such a scheme would result in an annual saving of about 1800 furnace hours, and that the corresponding annual output would be increased by about 8000 tons.

Supply Systems

There are two methods of supplying scrap to open-hearth furnaces in common use: bench loading and stage railway. The relative merits of these systems have been discussed in detail by Diamond and Frankau.†

Bench Loading Systems—As preference today is given to stage railways, the comments in this section will be confined to a few general principles.

Storage Capacity—The main disadvantage of the bench system is the limited storage capacity for loaded pans. Diamond and Frankau share this opinion and have suggested a means of overcoming this difficulty

Scrap Loading Cranes—The limited storage capacity of bench systems must be compensated by installing considerable loading capacity. As in the case of the stage railway system, it is important that magnet cranes should have first-class maintenance to help avoid breakdowns; failure of a crane can have serious repercussions on furnace charging

Scrap Wagons—The marshalling of wagons in the scrap bay plays a very important part. Groups of wagons are allocated to specified furnaces, which means

* This requirement of mixing scrap represents a practical improvement on conditions obtaining in most shops, where the quality of the scrap loaded bears little relation to the current requirements of the furnaces, bunching or no bunching. A further improvement would be to load scrap which is only just good enough to prevent charging delays during slack periods between bunching, and to use the better scrap for pre-loading into pans in readiness for bunching and during the actual bunching. This rule is a refinement which may be too complicated to adhere to as a general rule, but which may well be worth adopting under exceptionally severe conditions.

† E. L. Diamond and A. M. Frankau, *J. Iron Steel Inst.*, 1949, vol. 161, pp. 191–211.

Table V
BOGIE RETURN TIME

Component	Time, min.*	
	Mean	Range
(i) Handled by charger	22	7–37
(ii) Empty in melting shop	47	0–113
(iii) Travel to scrap shed	5	5
(iv) Loading in scrap shed	30	15–45
(v) Travel to stockroads (incl. weighing)	15	7–23
Total return time	128	57–199

* These times are for complete rakes of bogies, not individuals

that each group of wagons must hold a suitable mixture of scrap. If this is not done certain furnaces may get more than their fair share of bad scrap and charging will be very slow

Weighing Scrap—A drawback of the bench system is the difficulty of weighing the furnace charge. The chief means of assessing the scrap charge is to allocate previously weighed wagon loads to specific furnaces. The method is laborious and requires careful supervision. Failure to do this often means estimating box weights, at best a very rough and ready method. Errors in estimating pan weights lead to variations in cast weights and hence to loss of output, as can be seen from the distribution of cast weights shown in Fig. 5, obtained from a large sample at a works where the scrap charge is estimated. Individual cast weights varied from 60% to 120% of the rated capacity of the furnaces; 13·7% of all casts were below 80% and the average cast weight was 92% of capacity.

Stage Railway Systems—As the name indicates, this is a rail supply system, and the difficulties which occur and which have to be overcome are those normally associated with rail traffic. As in all rail systems, it is found that the delays which arose occurred almost invariably at the terminals. These are due to the slow loading of scrap, shunting difficulties, badly loaded pans, the slow return of empties, and the low availability of locomotives. The best way to check the efficiency of the service is to make a time study of all bogie movements and to break down cycle times into their various components.

The cycle time of a bogie is defined as the time elapsed between two successive weighings of the same bogie. This includes the time spent full on the stock-roads, which at one works was observed to vary between 10 min. and 12 hr. Since, however, the object of a supply system is to provide a stock of full bogies standing ready for the chargers, cycle time cannot be used as a measure of efficiency if it includes the time spent full on the stockroads. A useful criterion of efficiency, therefore, is obtained if the time spent full on the stockroads is excluded from the cycle time. This may be defined as the ' return time.'

Return time should be as short as possible consistent with good pan weights. Its components are set out in Table V; the values are given as an example of conditions in a melting shop with a stage railway:

(i) The time during which rakes are handled by the charger depends on the speed of the machine and can only be reduced by shortening the rakes

(ii) The time empty in the melting shop can generally be substantially reduced. Empty bogies must be removed from the stage as fast as possible. Whenever a magnet crane is standing idle, it is particularly important to move empty bogies to the loading bay with the least delay, even if this means that a charger must interrupt its work to clear a road for the locomotives: less harm is done if a charger is delayed 3 or 4 min. than if empty bogies and an unemployed crane have to wait 10 or 20 min. while the charger finishes its work. It is just as important to remove empty bogies from the melting shop with the least delay in slack periods as during bunching, since the demands of bunched furnaces can only be met from pre-loaded bogies

(iii) Little time is normally lost during travelling and weighing

(iv) Little time is normally lost during loading. Care, however, must be taken not to gain speed at the expense of good pan weights

Full bogies, once allocated to a furnace, are often kept on the stage for lengthy periods. This practice arises from the not entirely unjustified fear melters have of losing their scrap unless it is standing in front of their furnaces. This practice should be discouraged, as on numerous occasions it was found to cause congestion on the stage.

The importance of keeping return time to a minimum is illustrated in Fig. 6*a*, which was prepared from data at a works where it was apparent that long return times were responsible for considerable charging delays. At the same time it was also possible to show (*see* Fig. 6*b*) the effect of the number of available bogies on charging delays. Figure 6*b* emphasizes the importance of keeping the maximum number of bogies in circulation: a bogie left for hours or even days in a neglected siding is worth as much as no bogie at all.

Experience shows that to expedite bogie movements stage locomotives must be under the control of the melting-shop staff. Only in this way can the essential high availability be achieved. It is difficult to get more than 4–5 hr. useful work per shift out of a steam locomotive owing to coaling, watering, and fettling operations. But 6½ and 7 hr. continuous working is not unusual for Diesel locomotives. There are cases where two Diesels are operating a shop where four steam locomotives would be required.

Shift Changeover

Whilst it is generally known that there is a slackening in activities at shift changeover times, the full extent of the consequent delays and loss of production is rarely appreciated. Shift changeover can be responsible for a considerable reduction of activity in

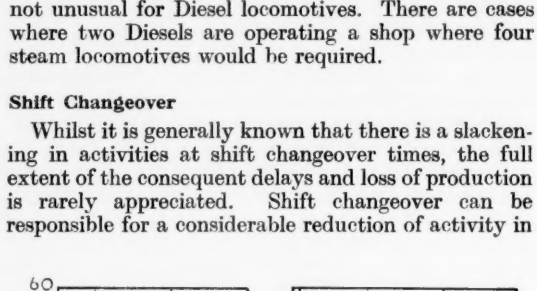


Fig. 6—Effect on mean charging delay of (*a*) bogie return time, (*b*) number of scrap bogies

melting shops, amounting at times to a complete stoppage of work. At one works it was found that in 50 complete charges, picked at random, some 5000 pans were charged; of these not one was recorded as having been charged between 5.10 A.M. and 6.20 A.M. At another works, in a sample of eleven days, only two trains of full bogies were delivered to the stage between 5 A.M. and 6 A.M., one train between 1 P.M. and 2 P.M., and no deliveries at all between 9 P.M. and 10 P.M. The mean delivery for all other hours of the day was seven.

Supervision

Many of the points discussed in the earlier sections of this paper—bogie traffic, scrap mixing, scrap loading, shift changeover practices, etc.—concern different aspects of taking scrap from the loading bays to the furnaces. Responsibility for these activities is often scattered among various people, all of whom act largely independently of one another. Under these conditions it is impossible to achieve co-ordinated action. Quick and efficient scrap supply demands that there should be one man whose sole responsibility it is to supervise and co-ordinate all the activities connected with loading and traffic. The absence of co-ordination is often the underlying reason why there is so much room for improvement in scrap supply systems, and it is therefore thought desirable that every melting shop should have a raw-materials shift foreman.

Such a foreman would be responsible for the ordering of shunts from the traffic department; he would have to know which furnaces are charging and how far advanced they are so that he can send to each furnace the correct materials at the right time; it would be his job to see that bogies are sent where they will be most quickly loaded and that they are loaded well; and he must ensure that the available cranes are used to the fullest possible extent. He would, in fact, be responsible to the shift manager for the whole of the supply side of the shop in the same way as the sample passer is responsible for the steelmaking side.

At some works the acquisition of some expensive item of capital equipment, such as a scrap press or a new scrap loading bay, is regarded as the panacea for excessive charging times. Whilst the tendency to pin one's faith on to costly new plant is understandable, virtually the same improvement can often be secured by using existing facilities to better advantage; this can only be done with effective supervision.

CONCLUSIONS AND RECOMMENDATIONS

Although every melting shop has its own particular problems, all suffer to a greater or lesser degree from charging delays, particularly at times of bunched charging, and all would benefit from faster charging and improved services.

Little can be done to prevent bunching, but heavier pan weights and better supply services can go a long way to reducing delays. The following points were found to apply to most of the melting shops investigated and are now put forward as general recommendations for improving charging times.

Inward Scrap

This should be carefully examined and marshalled by grade. Scrap should never be put to stock indiscriminately, especially in a loading bay. Correct marshalling of wagons is essential when these are to be unloaded directly into pans.

Pan Weights

Good pan weights make for fast charge times and help to keep charging delays down to a minimum. Good team work between crane drivers and trimmers contributes to better pan weights and to a tidier shed.

The delays suffered by charging bad scrap for a period more than outweigh the time saved by subsequently charging heavy scrap; light and heavy scrap should therefore be loaded in fairly rapid succession. Furthermore, wherever possible overall pan weights should be increased by dropping heavy scrap, such as mill scrap, on top of shearings and similar light materials.

Shearing and flame cutting make it possible to load that portion of scrap which could otherwise not be loaded at all, but are of limited application thereafter. Pressing, by contrast, can deal with large tonnages, increasing the density of scrap by a factor of 2–3, but at a cost of 7*s*. 6*d*. to 14*s*. 6*d*. per ton; it must therefore be balanced against the possibility of buying better scrap.

Scrap Storage and Loading Operations

Since bunched charging and slack periods alternate, the slack periods must be used to build up the largest possible stock of scrap for the next period of bunched charging. This requires careful management of bogie traffic and loading operations.

Empty bogies must be removed from the stage as soon as possible after charging and returned straight to the scrap shed for reloading. The corollary to this is that no magnet crane should be idle when there are empty bogies anywhere in the shop. It is not good enough to start loading hurriedly when there is a call for scrap. It is quite as important to *load* scrap as it is to *charge* it, and empty pans must be taken to the loading bays just as urgently as loaded pans to the furnaces.

Whenever magnet cranes would otherwise be idle, locomotives must have right-of-way over chargers; because of the overriding importance of keeping bogies on the move and keeping the cranes as fully occupied as possible, chargers must be prepared to interrupt their own work and to clear a way for the locomotive.

Emergency Scrap Reserve

A small number of bogies loaded with particularly heavy scrap should be set aside as a reserve for use only during emergencies, such as periods of particularly severe bunching or lengthy traffic hold-ups. Such a reserve would also be valuable at weekends when the closing-down of mills tends to reduce the overall scrap density.

Locomotive Availability

Melting-shop locomotives should be under the

authority of the melting-shop manager. High availability is essential and can only be assured if locomotives are allocated unconditionally to the melting shop.

Shift Changeover

It may be difficult to do much about delays suffered at shift changeovers; one should, however, know what they amount to. Failure to keep a check on these delays can result in loss of production and loss of morale. Shift changeover can be responsible for a considerable reduction of activity in melting shops, amounting at times to a complete stoppage of work.

Supervision of Raw Materials

Equipment and layout are often blamed for difficult melting-shop operation. Poor equipment and bad layout can, indeed, make things very awkward, but this can often be largely compensated by close (and especially by well-planned) supervision.

The appointment of really first-class raw-materials shift foremen in steelworks would pay handsome dividends. They should come under the melting-shop manager and should be responsible for all allocation and deliveries of scrap, marshalling operation, scrap preparation, loading and trimming, bogie utilization, storage, and traffic control.

Charging Delays Due to Furnace Bunching

A METHOD OF ASSESSMENT

By R. Solt, B.Sc., A.M.I.E.E., A.M.I.Mech.E.

SYNOPSIS

This paper sets out an operational analysis of charging open-hearth furnaces. In most melting shops the changing demand of the furnaces occasionally exceeds the capacity of the supply system and charging will be delayed. It may pay to install more equipment in order to reduce charging delays; any such decision should be based on an evaluation of the charging delays suffered under existing and under proposed conditions. A method of evaluation is set out in the paper. The changing demand of the furnaces can be forecast by using an approximate probability theory. 1082

THIS paper describes the theoretical background to a number of investigations which have been carried out into scrap supply systems for open-hearth furnaces. The general conclusions which have emerged from these investigations are discussed in a companion paper.*

Because of the variability of furnace cycle times there are in any melting shop frequent occasions when a number of furnaces become ready to be charged at the same time or in rapid succession. When such 'bunching' becomes severe it may be impossible to supply scrap to the furnaces at the rate at which they are demanding it. A measure of bunching has now been defined in terms which will allow the demands of the furnaces to be related to the capacity of the charging system. This makes it possible to determine the total charging delay that will be suffered by a melting shop under existing or proposed conditions.

BUNCHING OF FURNACES

Figure 1 illustrates the incidence of charging which might occur in a five-furnace shop in any 14-hr. period; it shows also the resulting charging rate for the whole shop.

To draw a record such as this it is necessary to know the charging time of the furnaces, their charging rate (tons/hr.), and the time when each furnace begins to charge. Such a record can only illustrate an isolated instance; it cannot be used to draw any general conclusions. For this a more convenient method is to record the intervals between successive furnaces beginning to charge: if a number of short intervals follow one another there will be a high degree of bunching.

In Fig. 1, for example, furnace *A* is the first to start charging; it is followed by *E* ½ hr. later; *C* follows after another ½ hr., etc. These intervals are set out in the first column of Table I. The following columns show time intervals not between succeeding furnaces, but between the first and the last of groups of furnaces: thus the next column (for groups of three furnaces) shows the time interval between any one furnace and the next but one. The composition of these groups is determined by time, not by space. This is made clear by reference to Table I; each furnace in turn is taken as the first of a group; furnaces are then included strictly in order as they begin to charge until the group complement is filled.

Table I is for a five-furnace shop. Since each furnace must complete its cycle before it begins to charge again, more than five furnaces cannot begin to charge in less than the minimum cycle time. Severe bunching cannot therefore continue indefinitely; when periods of heavy bunching occur they must alternate with slack periods.

The worst possible bunching would obviously obtain

* M. D. J. Brisby and W. O. Pendray, *J. Iron Steel Inst.*, 1955, vol. 179, March, pp. 252–260 (this issue).

Paper SM/A/122/54 of the Steel Practice Committee of the Steelmaking Division of the British Iron and Steel Research Association, received 18th November, 1954. The views expressed are the author's, and are not necessarily endorsed by the Committee as a body.

Mr. Solt is on the staff of the Association's Operational Research Section.

if all furnaces started to charge at the same time. In practice, this is most unlikely to occur. On the other hand, it is quite probable that some of the furnaces will become ready for charging in rapid succession. In the example in Fig. 1 there were two occasions when two furnaces followed one another at ½-hr. intervals, three more occasions when they followed one another in 1 hr., etc. This information can be presented in the form of a frequency distribution of charging intervals. There will be further distributions for groups of 3, 4, 5 . . . N furnaces, where there are N furnaces in the shop. A set of such distribution curves is shown in the Appendix (Fig. 6).

When investigating a melting shop which has been in normal production for some time the necessary information can be extracted from past furnace records.* The analysis, which must be based on a sufficiently large sample, shows the relative frequency (and therefore the relative importance) of various bunching conditions.

The frequency distributions obtained show the probability with which a given proportion of all furnaces in a shop will begin to charge in a given time. So, for example, in a seven-furnace shop the interval between succeeding charges will be greater than 1½ hr. and less than 2½ hr. in probably 20% of all cases; the likelihood that a third furnace will begin to charge in the same interval is only 15%, and that of a fourth furnace is only 5%.

ABILITY OF CHARGING SYSTEM TO MEET DEMAND

The demand of the furnaces is presented in the form of a charging-rate/time diagram drawn for a group of furnaces. By way of illustration, Fig. 2 shows the case of four furnaces beginning to charge in 2 hr. (*i.e.*, the fourth furnace 2 hr. after the first), assuming that the furnaces begin to charge at regular (40-min.) intervals.

The area of Fig. 2 represents the total scrap weight (tons) of the four charges. If all this weight is loaded in boxes standing by the furnaces at the start and

* There are occasions when no records of past performance are available. To deal with these cases an equation has been evolved which allows a theoretical solution to be applied to local conditions. Details of the method are given in the Appendix.

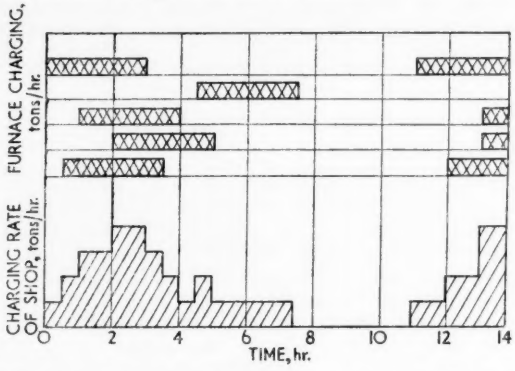


Fig. 1—Incidence of charging in a 5-furnace shop, and resulting shop charging rate

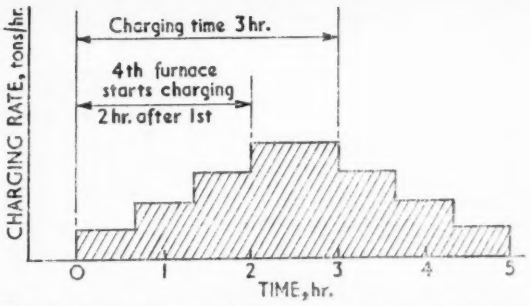


Fig. 2—Four furnaces beginning to charge in 2 hr.; shaded area represents total weight charged

if the chargers, etc., can handle the boxes fast enough, the furnaces can certainly be kept supplied without delay.

Since periods of bunched charging must alternate with slack periods, it should always be possible to meet peak periods with all available boxes standing ready under load. It is unlikely, however, that enough charging boxes will be available for bunched charges to be supplied entirely from pre-loaded scrap. The problem is then to balance the storage capacity and the replacement capacity of the supply system so that the demands of the furnaces can be adequately met.

To solve this problem the following data must be known:

(i) *Furnaces:*

'Normal charging time,' *i.e.*, the time in which furnaces should be charged	t_c hr.
Average charging rate; although charging of furnaces is a batch process, the present method allows it to be regarded as continuous without any loss of accuracy	W_c tons/hr.

(ii) *Supply System:*

Number of charging boxes available	n
Average weight of scrap per box; where this varies widely from charge to charge it should be presented as a frequency distribution of 'average box weight' (*i.e.*, averaged over complete charges)	W tons
'Return time' (*i.e.*, the average time needed by any one box to complete an operation cycle). This includes the average loading and charging time per batch of boxes,† the transport times between loading area and the furnaces, and the average delay times waiting for transport. It excludes 'waiting for	

† Boxes are normally loaded and charged in batches; each box is therefore involved for as long as is needed for the entire batch.

Table I

TIME INTERVALS FOR GROUPS OF FURNACES BEGINNING TO CHARGE

Number of Furnaces in Group	2	3	4	5
Time interval between first and last furnace in group beginning to charge, hr.	½	1	2	4½
	½	1½	4	10½
	1	3½	10	11
	2½	9	10	11
	6½	7½	8½	8½
	1	2	2	
	1	1		
	0			

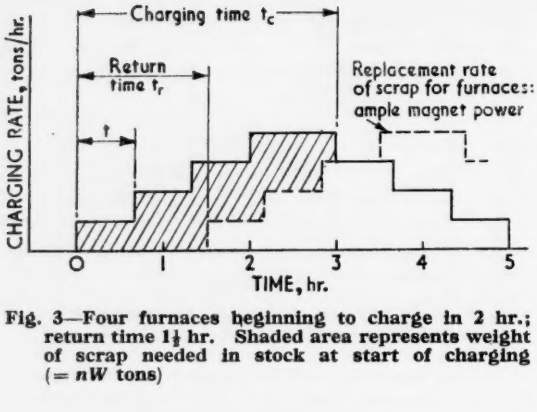


Fig. 3—Four furnaces beginning to charge in 2 hr.; return time 1½ hr. Shaded area represents weight of scrap needed in stock at start of charging (= nW tons)

demand' times (*i.e.*, waiting times incurred because the furnaces are full, or because the loading cranes are occupied)	t_r hr.
Max. charging rate of charging machines	boxes/hr. or tons/hr.
Max. loading rate of magnet crane	boxes/hr. or tons/hr.

It is evident that r furnaces can be supplied without delay in any circumstances* (even if they all start to charge at the same time), provided that

$$rt_cW_c \leqslant nW \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

As charging proceeds, each batch of boxes emptied into the furnaces will be taken away for loading and returned to the furnaces as quickly as possible; the length of this operation has been defined as the 'return time' t_r. Provided that the return time is less than the charging time (which is usually the case), r furnaces can always be supplied without delay as long as

$$rt_rW_c \leqslant nW \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Figure 3 shows four furnaces beginning to charge in 2 hr. (as in Fig. 2), with a return time of 1½ hr. The weight needed in stock at the start of this bunched charging period is much less than the total weight charged, as shown by the shaded portion of the area in Fig. 3.

In practice every supply system must be able to satisfy a proportion of the furnaces fed by it, even if they start charging at the same time, and the condition of equation (2) will hold for several values of r. Suppose R is the greatest value, *i.e.*, the greatest number of furnaces in a melting shop which can be supplied without delay, even if they begin to charge simultaneously. These R furnaces will consume Rt_rW_c tons of scrap from the stock initially available; there will be a residual of $(nW - Rt_rW_c)$ tons which can be used for any further furnaces. By definition of R,

$$(nW - Rt_rW_c) < t_rW_c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

If $(R + 1)$ furnaces start charging together, the $(R + 1)^{th}$ furnace must therefore suffer delay. If, however, the furnaces become ready for charging at (assumed equal) intervals t, so that the $(R + 1)^{th}$ furnace starts Rt hr. after the first, no delay will occur provided that

$$(nW - Rt_rW_c) \geqslant (t_c - Rt)W_c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

(this is evident from the geometry of Fig. 3). In this instance the shortest time interval by which the $(R + 1)^{th}$ furnace can follow the first furnace without suffering any delay is given from equation (4) as

$$Rt = Rt_r + t_c - n(W/W_c) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

This shortest time interval is termed the 'critical time.' For groups of r furnaces up to but not greater than R, the critical time is zero. For the $(R + 1)^{th}$ furnace, it is given by equation (5).

For the $(R + 2)^{th}$ furnace, the critical time $t_{c(R+2)}$ can similarly be arrived at by reference to the relevant bunching configuration, and so on to the N^{th} furnace.

The necessary equations are best developed individually for each problem. This ensures that they are applied with a clear understanding of the physical significance of the quantities involved, which is particularly important when limitations to the loading rate of the magnet cranes must be taken into account. The effect of this limitation is illustrated in Fig. 4. It shows the interdependence of loading rate, storage capacity, and return time in determining the capacity of a charging system.

CHARGING DELAYS

The critical time for a number of furnaces beginning to charge has been defined as the shortest interval between the first and last beginning to charge which will allow charging to proceed without delay: when the time interval is greater the charging system can cope with the bunching without being used to its full capacity; when the interval is shorter, delay will occur. This delay is such that every time the r^{th} furnace is ready for charging in less than the critical time $t_{c(r)}$, it will be delayed until that interval obtains.† If, for example, the r^{th} furnace started to charge t_a hr. after the first furnace, it would be kept waiting for scrap to the extent of $(t_{c(r)} - t_a)$ hr. in the course of its charge.

* In practice it will almost invariably be found that the capacity of the chargers is ample compared with that of the other parts of the system.

† This is not necessarily the case in practice, but the assumption simplifies the calculations. If required, the method can be adapted to take account of the more usual working practice whereby furnaces are charged as soon as they become ready and as long as scrap is available.

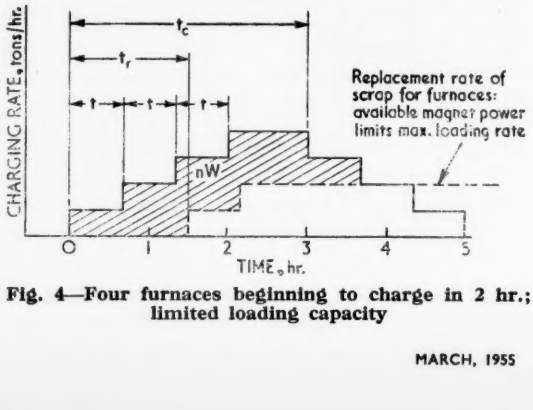


Fig. 4—Four furnaces beginning to charge in 2 hr.; limited loading capacity

In practice, it is not necessary that only the last furnace to start charging should be held up; the delay can be—and usually is—shared out amongst all the furnaces then on charge, but the effect in total furnace hours lost is the same.

How often the r^{th} furnace becomes ready for charging in less than $t_{c(r)}$ after the first is shown by the relevant frequency distribution (*see* pp. 260–261 and Fig. 6 in the Appendix). An enlarged portion of such a frequency distribution is shown in Fig. 5.

The frequency of delays is given by the area bounded by the curve and by the ordinate at $t_{c(r)}$ hr. It is therefore the sum of all the probability elements $p(t)\delta t$, whilst t is varied from $t = 0$ to $t = t_{c(r)}$.

On each occasion the delay time experienced is given by

$$t_d = t_{c(r)} - t_a \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

and for each interval t_a this will occur with a frequency of $p(t_a)\delta t$. The total charging delay suffered by the r^{th} furnace is therefore

$$T_{d(r)} = \int_0^{t_{c(r)}} (t_{c(r)} - t)p(t)dt \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Any furnace, however, which begins to charge as the r^{th} after the first is also the $(r-1)^{th}$ after the second, and there must be some overlapping of these groups. This will in fact happen whenever $t_a \leqslant t_{c(r-1)}$. To avoid reckoning these delays more than once, equation (7) is amended by changing the limits of integration. It now becomes

$$T_{d(r)} = \int_{t_{c(r-1)}}^{t_{c(r)}} (t_{c(r)} - t)p(t)dt \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

This is the first moment about the ordinate at $t_{c(r)}$ of the area bounded by the curve (Fig. 5) and by the ordinates at $t_{c(r)}$ and $t_{c(r-1)}$. Where actual frequency distributions are available $T_{d(r)}$ can be derived by geometrical approximation. As an alternative the expression for $p(t)$ is (*see* Appendix)

$$p(t) = \frac{(N-1)!}{(r-2)!\,(N-r)!}\, T^{(1-N)} t^{(r-2)} (T-t)^{(N-r)} \ldots (9)$$

Substituting for $p(t)$ in equation (8) gives the mean charging delay as

$$T_{d(r)} = \frac{(N-1)!}{(r-2)!\,(N-r)!}\, T^{(1-N)} \int_{t_{c(r-1)}}^{t_{c(r)}} (t_{c(r)} - t) t^{(r-2)} (T-t)^{(N-r)} dt \ldots\ldots (10)$$

When actual figures are substituted, this expression can be expanded for integration. Alternately, it is readily expressed in the form of an incomplete beta-function for which the solutions are tabulated.*

A value for $T_{d(r)}$ can thus be found, giving the average charging delay in the shop by virtue of bunching in groups of r furnaces. The average can similarly be found for groups containing different numbers of furnaces, with r varying from $r = 2$ to $r = N$.

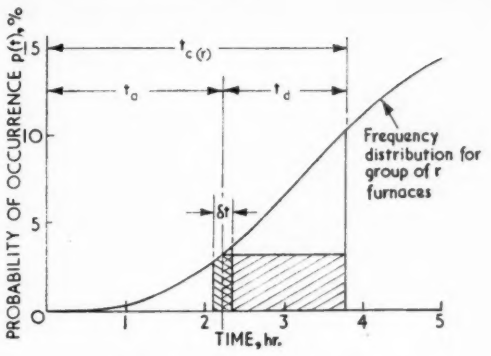


Fig. 5—Charging delays

The average delay per charge is finally given by:

$$T_{d(\text{av.})} = \sum_{r=2}^{r=N} T_{d(r)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

APPENDIX

Bunching of Furnaces: Theoretical Treatment

In the preceding text, the severity of bunching has been defined by the charging rate and charging time, and by the interval between the first and the last of a number of furnaces beginning to charge. In melting shops in which the furnaces are similar to one another, the charging rates and charging times are constant and the same for all furnaces. The degree of severity experienced therefore depends on how quickly furnaces begin to charge one after another on any given occasion. The problem is to find how often different degrees of severity can be expected.

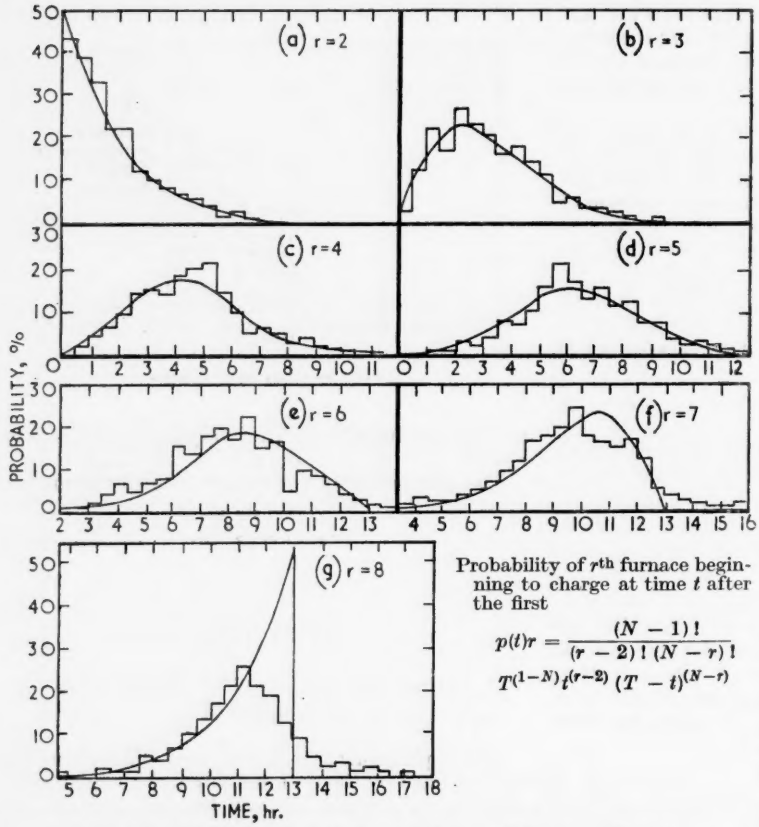
It will be assumed that the charge-to-charge time T is constant and the same for all furnaces, so that all furnaces will begin to charge once at some time during any period T. It is further assumed that the times at which furnaces begin to charge are randomly distributed within the period T.† Suppose that the time at which any one out of N furnaces begins to charge is taken as the datum for such a period; then $(N-1)$ furnaces must start charging in the next T hr. In order that an r^{th} furnace shall start charging in a time interval δt, t hr. after the first, two conditions must be simultaneously satisfied:

(i) Any one of $(N-1)$ furnaces must begin to charge in time δt which is specified as occurring t hr. after the first

(ii) Of the now remaining $(N-2)$ furnaces, $(r-2)$ must begin to charge in time 0 to t, and $(N-r)$ in time t to T.

* K. Pearson, (ed.), "Tables of the Incomplete β Function" : Cambridge University Press.

† These are necessary simplifying assumptions; it is naturally well known that the charge-to-charge time is variable, and the error due to assuming it constant becomes evident in Figs. 6*f* and *g*.



Probability of r^{th} furnace beginning to charge at time t after the first

$$p(t)r = \frac{(N-1)!}{(r-2)!\,(N-r)!}\,T^{(1-N)}t^{(r-2)}\,(T-t)^{(N-r)}$$

Average cycle time $T = 13$ hr., total no. of furnaces $N = 8$

Fig. 6—Bunching of furnaces: comparison of theoretical results (smooth curves) with actually observed results (stepped lines). Sample size 520

The probabilities with which these conditions will be fulfilled can be established; their product gives the probability that the r^{th} of N furnaces will begin to charge t hr. after the first.

The probability that any one of $(N-1)$ furnaces begins to charge in a time interval δt (specified to occur t hr. after datum time where t can vary from 0 to T) is:

$$\frac{N-1}{T}\,\delta t \qquad \ldots\ldots(12)$$

The individual probability that any furnace begins to charge in time 0 to t is

$$X = \frac{t}{T}$$

and that it should begin to charge in time t to T is:

$$Y = \frac{T-t}{T}.$$

The probability of r occurrences in a set of N independent events is

$$\frac{N!}{r!(N-r)!}\,X^r Y^{(N-r)} \qquad \ldots\ldots(13)$$

where X is the individual probability of an occurrence and Y that of a non-occurrence.

The probability of $(r-2)$ out of $(N-2)$ furnaces beginning to charge in time 0 to t is thus

$$\frac{(N-2)!}{(r-2)!\,(N-r)!}\left(\frac{t}{T}\right)^{(r-2)}\left(\frac{T-t}{T}\right)^{(N-r)} \qquad \ldots\ldots(14)$$

The probability of the r^{th} out of N furnaces beginning to charge t hr. after the first is given as the product of equations (12) and (14):

$$p(t)\delta t = \frac{(N-1)!}{(r-2)!\,(N-r)!}\,T^{(1-N)}t^{(r-2)}(T-t)^{(N-r)}\delta t \qquad \ldots(15)$$

In this expression N is the actual number of furnaces and T is the known (average) charge-to-charge time. For each value of r, t can be varied (over the range 0–T) to give the probability $p(t)\delta t$ of the r^{th} furnace beginning to charge in a time interval δt, t hr. after the first.

The appropriate curves can be obtained by substituting successive values for t in the probability density function given by equation (15) with δt given unit value.

To confirm the validity of equation (15), the theoretical curves have been compared with actual melting shop histories. One such comparison is shown in Fig. 6, in which the actual distribution was obtained from 5 weeks' operation of an eight-furnace shop (*i.e.*,eight furnaces always working).

There are two types of systematic variation between the actual and theoretical curves of Fig. 6: in the middle range of r values (*i.e.*, $r = 3$ to $r = 6$) the actual distributions are more peaky than the theoretical. This means that furnaces tend to be spaced more evenly than would be the case if they were altogether independent. This spacing may partly be due to intentional de-bunching, *i.e.*, the furnaces are scheduled to some extent. It may also be due to forcible de-bunching, *i.e.*, furnaces are sometimes spaced out by virtue of delays which occur due to bunching.

In the higher ranges of r, when $r = 7$ and particularly when $r = 8$, the actual distributions tail off to much higher intervals than the theoretical. This is due to the variations in cycle time which occur in practice, whilst the theoretical curves are drawn on the assumption of a constant cycle time. For the purpose of finding the effect of bunching, however, only the likelihood of short intervals arising is normally of interest, *i.e.*, the left-hand portions of the curves. At that end agreement between theory and practice seems to be good.

DISCUSSION ON PAPERS

DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

Special Meeting in Sweden, 1954

A SPECIAL MEETING OF THE IRON AND STEEL INSTITUTE was held in Sweden from Monday, 7th June, to Friday, 18th June, 1954, by invitation of the President and Council of Jernkontoret. A Joint Technical Session was held at Riksdagshuset, Stockholm, on Saturday, 12th June, at which papers by British and Swedish authors were presented and discussed. The first group of papers were on the pelletizing of iron-ore concentrates and the second on low-alloy steels. The discussion on the first group is presented below; that on the second group was printed in the February issue of the *Journal*.

DISCUSSION ON PELLETIZING

This discussion was based on the following papers, which were published in the May, 1954, issue of the *Journal:*

"Aspects on Pelletizing of Iron Ore Concentrates," *by M. Tigerschiöld* (pp. 13–24).

"The Development of a Pelletizing Process for Fine Iron Ores," *by J. M. Ridgion, E. Cohen, and C. Lang* (pp. 43–63).

"The Pelletizing of Northampton Sand Ironstones by Vacuum Extrusion. The Experimental and Pilot Plants at the Corby Works of Stewarts and Lloyds Ltd.," *by A. Stirling* (pp. 25–42).

Dr. **Magnus Tigerschiöld** (Trafikaktiebolaget Grängesberg-Oxelösund and Luossavaara-Kiirunavaara AB, Sweden), in introducing his paper, pointed out that in the key to Fig. 1 of his paper (p. 17), the words ' Oxidation of hematite ' under heading (i) should read ' Oxidation of magnetite.'

Mr. **J. M. Ridgion** (B.I.S.R.A.) introduced the second paper and Mr. **A. Stirling** (Stewarts and Lloyds Ltd.) the third.

Mr. **F. H. Saniter** (United Steel Companies, Ltd.): The Symposium on Sintering which the Institute organized in London last November focused attention on one method of agglomerating fine ores and concentrates. Now we are considering another approach, namely pelletizing. At first sight, the two techniques are quite different, the sponge-like structure of sinter contrasting strongly with that of compact spherical pellets. Yet, are the two approaches so very different? The Symposium papers drew attention to the vital importance of permeability just after the ignition of the sinter bed. Voice and his co-authors* showed that attention to this factor alone had nearly doubled the output of one Dwight-Lloyd plant operating on low-grade British ores. Grice and Davies† showed that the successful feed preparation of such ores involves not only mixing of the various constituents, but also a process of small-scale pelletizing. Given proper moisture control, the extreme fines adhere to each other and to the coarser particles, so producing balls up to 5 mm. or more in diameter. In one series of trials on a Greenawalt plant, this pelletizing was enhanced so that all material below 2 mm. coalesced in this way and, as a result, sintering time was reduced by one-third as compared with normal practice.

Further laboratory work on these ores showed that, so far as the rate of sintering was concerned, pelletizing of the sinter feed beyond an average size of roughly 5 mm. gave little further benefit, since ' air ' consumption per ton of feed then increased rapidly, as much air was drawn through the large pores in the bed without affecting the combustion of the coke. Moreover, with these low-grade ores, feed coarser than this limit does not sinter thoroughly.

Up to the firing stage, the difference between the two processes is thus one of degree, the pellets in sinter feed being generally smaller than those produced by pelletization on the Swedish and American pattern.

* E. W. Voice *et al*, *J. Iron Steel Inst.*, 1953, vol. 175, Oct., pp. 97–152.

† M. A. K. Grice and W. Davies, *ibid.*, pp. 155–160.

The sinter maker, seeking a strong yet porous product, deliberately operates at such a temperature that the minute pellets fuse together, thus losing their identity in the formation of the resultant sponge-like structure. In Swedish and U.S. practice, the pellets are fired in shaft kilns at a rather lower temperature, firing being controlled so that the pellets do not lose their shape and, as far as possible, are discharged as individuals. Woody has recently described a combination of the two processes in which relatively large pellets are fired on a modified sinter strand instead of in a kiln, the product discharging either as individual pellets or as agglomerates thereof.

Against the background of the London and Stockholm papers it is reasonable to ask whether fired pellets are intrinsically more desirable than sinter. Dr. Tigerschiöld notes that in the blast-furnace "pellets are superior to the hard burned sinter common in the U.S.A." I hope that he will be able to give us further guidance. The excellent sinter made at Domnarvet is often used as a standard by which British sinter is judged. Has anyone tried a 100% pellet burden and compared it with one composed entirely of such good sinter? The spherical shape of the pellets may facilitate stock descent, but on the other hand good sinter appears to present a greater surface to the reducing gases. Could Mr. Ridgion amplify the comment in his paper that "The observed superiority of pellets over sinter, in regard to porosity and degree of oxidation, suggests that improved blast-furnace efficiency may well be a vital factor." This seems to be in favour of pelletization. Swedish practice places great emphasis on well-oxidized sinter; Dr. Tigerschiöld remarks that normally more than 90% of the iron is present as hematite, so that pellets can scarcely be much better in this respect. How big is the gain in porosity?

These questions are far from academic, as many British ironworks depend on imported ore supplies, which contain an ever-increasing proportion of fines and concentrates.

Assuming that there is little to choose in blast-furnace operation between a 100% pellet burden and a 100% sinter burden, do the papers suggest which is the more efficient means of agglomeration? Dr. Tigerschiöld envisages pelletizing as a means of agglomerating extremely fine concentrates and suggests that in some cases pelletizing will be cheaper, because such materials sinter very slowly.

With this in mind, I have attempted to make a rough comparison between the merits of pelletizing as described in the present papers and the sintering of rich ores at Workington on a Greenawalt plant. In terms of heat required, sintering needs nearly twice as much as the firing of pellets. Expressed in terms of fuel costs, however, the position is reversed, sintering being much cheaper than pelletizing on the basis of fuel prices obtaining in England. How does this compare with Swedish experience? So far as power consumption is concerned, the picture is less clear. Sintering requires rather more air per ton of feed and, owing to the finer bed structure, this must be moved at a higher suction than is necessary for pellets fired in a shaft kiln. Some ores (such as Sierra Leone) must be ground before pelletizing will develop satisfactorily, involving substantial power costs; others, as a result of the concentration technique used, are sufficiently fine in themselves. On balance there may be little to choose between pelletizing and sintering in terms of fuel and power.

Pelletizing has been brought to its present state of perfection by close control of every stage of the process. First of all, the material must be reduced to a particular degree of fineness before it will ball up satisfactorily. In the next stage, that of pelletizing, the moisture content must be controlled within close limits to yield green balls of requisite strength. Finally, the pellets have to negotiate Dr. Tigerschiöld's 'Scylla and Charybdis' during firing: a little too much heat will fuse the balls together, whilst insufficient heat will yield a weak product. The process is above all one of precision.

Now contrast this with sintering. Little control of the size grading of the raw material is necessary, although plant operators usually try to avoid an excess of extremely fine concentrates, as these tend to reduce plant output. Permeability may vary within fairly wide limits. There is a wide range in the maximum temperature attained at different levels in the bed. Nevertheless, sintering has sufficient latitude to deal with a variable mixture of ores of different fusion points, whereas pelletizing demands a feed with a uniform fusion point. With rich magnetite ores sintering will convert magnetite to hematite as well as shaft-kiln firing of pellets of the same ores. On the whole, sintering seems to be a relatively crude but very versatile process.

Having this in mind, one wonders how sintering will develop as a result of the present phase of intensive research. Now that the technique of pelletizing fine concentrates has been mastered, there appears to be a good case for the process combining small-scale pelletizing and firing on a sinter strand in place of the shaft kiln. Dr. Tigerschiöld's figures indicate that the throughputs of both the pelletizing drum and the shaft kiln decrease seriously as the pellet size increases. Instead of accepting a small production of large pellets, could the pelletizing drum not be used to supply a large output of pellets, say of 3–5 mm. dia.? Such small pellets could be charged to the sinter strand, where they would be subject to less vertical load than in the shaft kiln, thus easing one of the critical factors. Based on the trials on British low-grade ores described by Grice and Davies,* a feed of this sizing should sinter very rapidly, thus overcoming the difficulty usually associated with fine ground concentrates.

It may be argued that more heat is required for sintering, but is this necessarily true? In the shaft kiln, much of the heat of the waste gases is recovered, but hitherto little attempt has been made to improve the heat economy of the sintering process. Lately we have been paying more attention to this. We already know that a substantial part of the total heat requirement for sintering may be saved by using preheated air and reducing the coke content of the feed. In this case the preheated air may be derived from the air-cooling of the finished sinter under forced draught, possibly supplemented by burning gas or oil in a large excess of air. In this way it is estimated that at least 20% of the fuel requirement may be saved. Moreover, by using preheated air, the bed temperature may be controlled to closer limits, so that instead of a mixture of soft and hard burned sinter, the product is of uniform quality, resulting also in less returned fines.

The paper on vacuum extrusion of Northants ironstone fines describes an ingenious technique which takes advantage of the clayey nature of much of this ore. As a ready means of agglomeration, it yields a product which apparently smelts as satisfactorily as the lump ore normally used. The composition of the agglomerate may be adjusted by the addition of limestone and rich ore fines.

Nevertheless, I wonder whether, in searching for a cheap method of agglomeration, the overall economy

*M. A. K. Grice and W. Davies, *op. cit.*

of ironmaking has not been somewhat neglected. At our Appleby-Frodingham plant we have operated on burdens containing 95% sinter for long periods and intend to adopt this practice on all our furnaces when our new sinter plant comes into operation. We are convinced that this course is justified, owing to the economy in the use of metallurgical coke and the greatly increased output of the furnaces.

We have been further encouraged in this direction by the sulphur removal achieved in sintering and the knowledge that the sulphur contents of both Frodingham and Northamptonshire ores will increase steadily in the future. I wonder what the future holds in store for Corby, and whether sulphur is likely to become an even more serious problem than it is at present?

To anyone with faith in the sinter process it seems wasteful to use the naturally arising fines for the manufacture of reconstituted stone and in so doing to throw away the opportunity for further beneficiation which sintering offers.

Admittedly, the Appleby-Frodingham and Corby conditions are somewhat different, particularly in regard to lime/silica ratio and slag volume, but it would be interesting to know what results would be obtained at Corby on the basis of 50% and 100% sinter in comparison with 50% and 100% extruded pellets. No doubt further work on the relative behaviour of sinter and extruded pellets in the blast-furnace is planned.

These papers make valuable contributions to the all-important subject of burden preparation. The blast-furnace is an expensive piece of equipment and there is no doubt that, given a burden with improved physical and chemical characteristics, it would respond by giving greatly improved output and fuel consumption. The availability of a variety of methods can only lead to further progress as a result of the best method being selected for each particular set of circumstances.

Mr. **L. O. Uhrus** (AB Svenska Kullagerfabriken, Hofors, Sweden): In Dr. Tigerschiöld's paper, it is stated that Swedish experience in pelletizing is connected with very finely ground magnetite concentrates used as raw material for the sponge-iron process. The use of hydraulic cyclons as classifiers before the drum filters in the concentration plants and the addition of calcium hydroxide as a binder are the most notable improvements during the last year.

The paper by Ridgion, Cohen, and Lang gives a great deal of information about pelletizing of hematite fines. In this case, the burning temperature has to be more than 150° C. higher than that needed for magnetite concentrates; 1450° C. is a very high temperature in a shaft kiln, and causes many problems in furnace design.

The paper states that in the Redcar kiln steady conditions are established in about 6–8 hr. In the pilot plant of about the same size which we have been operating for 3½ years we have found that 30–35 hr. are needed. We had a lot of trouble in this respect during the first months, as the kiln was stopped during week-ends. Steady operating conditions could not be maintained until a continuous four-shift system was in operation.

In the discussion of the heat balance in the paper it is stated that recuperation of the air in the kiln shaft would not be a practical proposition. From a purely theoretical point of view it can be shown that recuperation will decrease the fuel consumption by about 8%, partly because the total amount of air required is decreased by about 13%. Even from the operation point of view, recuperation of the air seems to be the right principle. It is not necessary to make a very sharp restriction to gas flow, as shown in Fig. 14*d*. The only disadvantage of recuperation when building a bigger kiln might be that some types of concentrate and some binders may produce dust and slag problems in the combustion chambers.

In the paper, oil is compared with other fuels and the figure of 9 gal./ton is mentioned. With recuperated air, oil consumption in Swedish pelletizing kilns is about 4 gal./ton, even with the slow operation which is necessary when making pellets for sponge-iron purposes. If pellets for feed ore or blast-furnace burden are produced from magnetite concentrates, oil consumption can be decreased to 2·7 gal./ton.

Dr. Ing. **H. Wendeborn** (Lurgi Gesellschaft für Chemie und Hüttenwesen m.b.H., Frankfurt-am-Main, Germany): Pelletizing is important for three reasons. Firstly, it is a complete solution of the transport problem for long distances and in all climates for all magnetite mines and producers of magnetite concentrates. Secondly, pellets of sizes over 1 in. made of high-grade ores are the right feed as oxidation ore for open-hearth furnaces and converters. Finally, pelletizing provides a good possibility for agglomerating calcines of flotated pyrites.

Pelletizing is not just a fashion, as is sometimes claimed, but is necessary and useful for the preparation of ores for special reduction processes. In general, however, it does not compete with the ordinary sinter process, which is never found in connection with mines, but is always as near as possible to the blast-furnaces. The latter also makes it possible to blend many different kinds of fine ore to form a self-fluxing burden as the best blast-furnace feed.

Dr. Tigerschiöld mentioned pelletizing by heat-hardening on a sinter machine and the Lurgi pilot pelletizing plant at Watenstedt. This plant was operated by Dr. C. Meyer and Dr. Rausch, and their experiences are being used to investigate certain considerations.

The present papers show how much experience has been gained in Sweden and the U.S.A. in the field of shaft-furnace pelletizing. The shaft furnace, however, requires special conditions from the ores, namely:

(i) Physical and chemical uniformity.

(ii) An appreciable difference between the sintering and smelting temperatures (to avoid sticking).

(iii) A certain resistance in the green and dried pellets to support the shaft pressure (abrasion of the pellets during charging and by the movement of the pellets against each other in the shaft).

These considerations are not of great importance for pelletizing on a sinter machine covered with a burner hood, for the following reasons:

(i) The burning temperature on the pelletizing sinter machine can be exactly regulated and controlled within limits of less than 10° C., and the optimum temperature conditions can be steadily maintained. No sticking of the pellets is likely.

(ii) The heating and cooling times are in the hands of the operator, who regulates the temperatures in the different zones of the hood according to the advancing speed of the sinter machine. The heating and cooling times are very important for the strength of the pellets.

(iii) Normally no additions to the ores, such as bentonite, lime, or salts, are necessary, except in cases where the shock temperature of the pellets must be increased for shortening the heating time. Bentonite does not increase the green strength, and the increase in strength of the green pellets is not necessary, because the pellet feed on a sinter machine has a depth of only about 12–20 in. Moreover, the pellets

remain in a state of rest and do not move against each other.

(iv) The production capacity of one unit is much higher with the sinter machine. The shaft-furnace capacity may be limited to 350–500 tons a day, as U.S. practice shows. But the first sinter machine has been working for three months in Babbit, Minn., and has an output of more than 1000 tons a day with a fuel consumption which is within the range of fuel consumption of the shaft furnace. When Dr. Tigerschiöld mentions that the size of pellets heat-hardened on sinter strands is comparatively small (about ½ in.), he may be right, but my Company have succeeded in producing good pellets of 1–1¼ in. easily in their pilot sinter plant. Larger pellets entail, however, a certain decrease in the production quantity.

The creation and development of the pelletizing shaft furnace is indeed an excellent basis, but at the same time it is only the first important step towards solving the pelletizing problem. The second, in my opinion, is the step from a furnace to a machine (*i.e.*, to the pelletizing sinter machine), especially for larger productions; the future of pelletizing belongs to those machines which can guarantee the most exact burning conditions and the highest productions per unit.

Mr. **Sven Fornander** (Jernkontoret, Stockholm): On behalf of the Research Organization of Jernkontoret I should like to congratulate Dr. Tigerschiöld on the very fine work he has done for pelletizing in Sweden. Research on this subject was taken up here on his initiative in 1946. Since then, acting as the chairman of our sub-committee for pelletizing, Dr. Tigerschiöld has been organizing all the research work. The good results obtained are to a very high degree due to the energy and enthusiasm which he has devoted to this matter.

The pelletizing of iron ore concentrates is particularly important to the Swedish industry. We have fairly large resources of ores which are easy to concentrate. The main point is perhaps, however, that iron-ore pellets in certain cases have a higher strength during reduction than ordinary sinter. This is of great significance to the production of sponge iron in a Wiberg furnace, and sponge iron is beginning to be produced in comparatively large quantities over here. It is true to say that sponge-iron making in Wiberg furnaces would not be possible save in a few selected cases without access to pelletized iron ore. The work Dr. Tigerschiöld has directed has therefore had important repercussions on the development of ironmaking in Sweden.

Monsieur **J. E. Astier** (IRSID, France): Up to the present we have carried out some laboratory and semi-industrial researches into the extrusion process, but we have not yet made any industrial tests. The researches were made first for the Institut de Recherches de la Sidérurgie by the Ontario Research Foundation in Toronto in 1951, and then by the research department of the Société Française de Céramique in 1951 and 1952 in Paris.

In France the development of the extrusion process has been considered in three ways. Firstly, extrusion may be treated as another way of balling or briquetting iron-ore fines in the pelletizing process. It is quite possible to make pellets by extruding the ore and balling the extruded product. Some tests along those lines have been made in the U.S.A., and several pelletizing pilot plants now include some equipment very similar to an extrusion machine (*e.g.*, the German pilot plants in Amberg and Herdhorf). It is possible that with soft ores like the Minette ores, some German sedimentary ores, and Northamptonshire ore extrusion would be more suitable than conventional balling in a drum.

Secondly, the extrusion process may be considered as an inexpensive way of agglomerating fine ores. In that field, Mr. Stirling pioneered the way by the use of raw pellets in blast-furnace burdens at Corby. Some French steel plants are interested in that process, since some Minette and Normandy ores (such as Soumont) seem to be quite suitable for the extrusion process. In this connection, it is necessary to emphasize the two methods of making pig iron:

(i) The use of a fully prepared burden, not only agglomerated in the physical sense but also in the chemical sense by removing moisture, combined water, CO_2, etc. It is a very expensive method, since the ore must be crushed, even if it is not possible to beneficiate it, and the whole burden must be sintered. The good results reported by Appleby-Frodingham and Domnarvet at the Symposium on Sinter held in London last year seem to indicate that, on the whole, pig iron can be produced easily in this way, owing to the increase in production and to the saving of coke in the blast-furnace.

(ii) The preparation of the burden in an inexpensive way, *i.e.*, by crushing and charging the fines in the furnace or agglomerating them.

It is very important to compare these two practices whenever production of pig iron is to be considered. I think that the former is, generally speaking, the more economical method; however, it is very difficult to justify this opinion in view of the inaccuracy of blast-furnace balances.

Finally, the extrusion process may be treated as being very suitable for agglomerating either iron ore or ore with coke breeze, charcoal, semi-coke, or even coal, for a low shaft furnace.

In regard to the last section of Dr. Tigerschiöld's paper, on 'Possible Future of the Pelletizing Process,' I wish to emphasize that the main bulk of research on pelletizing has been made on:

(i) Fine magnetite concentrates in the U.S.A. and Sweden

(ii) Some hematite ore in the U.S.A. and the U.K.

(iii) Pyrites cinders.

There is, however, now another field for the pelletizing process, namely, the agglomeration of sedimentary fine iron ores such as Minette, Ordovician, or Silurian iron ores (*e.g.*, Soumont). The important fact we discovered was that it was possible to pelletize those fines with a far coarser size than the magnetite concentrates. We were able to pelletize Soumont ore ground to 3 mm., which should be compared with about 100 or 200 mesh for magnetite concentrates or Sierra Leone hematites.

That seems to indicate that it would be possible in the near future to consider the pelletizing process for the agglomeration of fine ores obtained by crushing and screening. If the crushed ore is to be screened at say, ½ in. or 10 mm., it is not much more expensive to grind the $-\frac{1}{4}$ in. or -10 mm. fines to ¼ in. or 6 mm. for sintering (as at Appleby-Frodingham), or to ⅛ in. or 3 mm. for pelletizing.

This is only a technical possibility; I do not have sufficient data to discuss the economic point of view, which is very important; it is. however, worthwhile to mention this possibility, which can open a new field for the pelletizing process.

CORRESPONDENCE

Mr. **J. M. Ridgion** (B.I.S.R.A.) wrote : Dr. Tigerschiöld's paper is an admirable summary of the work of so many Swedish laboratories, pilot, and full-scale

plants. The studies of pellet strength as a function of degree of reduction are of particular interest, as little attention has been paid to this in the U.K., where the manufacture of sponge iron is not in question.

The heat-balance figures (p. 21) are most instructive and throw light on an important difference between magnetite and hematite practice. Whatever the overall heat balance of a pelletizing kiln may be, it is necessary at some stage to provide sufficient heat to raise the pellet temperature to the order of 1200° C. Dr. Tigerschiöld's figures lead to the following balance for the heating-up stage in the process:

	M.cal.
Heat Requirements:	
Sensible heat of 1000 kg. of pellets at 1150° C.	240
Heat to top gas and to evaporate water	165
	405
Heat Input:	
From combustion of fuel	147
From oxidation reactions	106
From sensible heat	10
From preheat in air (by difference)	142
	405

Thus, even with the low figure of 1150° C., preheat of air passing up the shaft must play an important role. This view is confirmed by the fact that Swedish plants introduce about 75% of the total air at the bottom of the shaft.

The statement in the B.I.S.R.A. paper (p. 57) that effective recuperation is not practical, which was rightly criticized by Mr. Uhrus, should therefore be restricted to hematite practice, for which, I believe, it retains its full force. With magnetite, the heat of oxidation plus the air preheat is sufficient to sustain full firing temperature in the central zone of the shaft and, indeed, offers a degree of control of uniformity of temperature across the shaft by varying the proportion of air introduced at the base.

Mr. **Carl Ludwig** (The Bonnot Company, Canton, Ohio, U.S.A.) wrote: Experience in the U.S.A. confirms Mr. Stirling's view that the particle-size distribution plus appropriate mixing or plasticizing gives more promise of strong economical agglomerates than the addition of so-called chemical binders. Of course, when the glues are available as wastes (such as in spent pickle liquor, paper-mill wastes, filter sludges, captured dust, etc.), it may be more practical to substitute cement additions in place of grinding or attrition mixing. We have plants which use both methods.

There are also times when loose mineral fines which are unwilling to be extruded can be blended with other stubborn samples, and the resulting mixture will feed well to the agglomerating schemes. In some non-ferrous size beneficiating systems this blending of presumed wastes is strategically arranged to serve two purposes. Firstly, the product is easier to package, and, secondly, the package or agglomerate is made to contain not only the basic ore but also the fuel or reducing agent. For instance, a carbide plant blends coal fines with waste calcium hydroxide, an elemental phosphorus plant adds coke breeze to phosphate rock, and a ferro-silicon flow sheet contains a station where coal, sand, and iron-ore fines are agglomerated into more convenient reactive slugs. Reaction rates are favourably influenced in all installations.

Appropriately, the extrusion machine appears to be the better tool to use when associating widely different mineral constituents. When examining the behaviour of a blend containing coal, after calcining or coking our extruded slugs, we found encouraging evidence of substantial fire bonding in some of the samples. Others with almost exactly similar chemical constitutions were quite weak and useless. This was hard to explain until we added a coke button test to measure the coal swelling characteristics as part of the blending for pyro-bonding techniques.

AUTHORS' WRITTEN REPLIES

Dr. **Tigerschiöld** wrote: The contributions to the discussion of the papers on pelletizing constitute a valuable supplementation of our knowledge in this field. Mr. Saniter asked a few questions which, however, are not easy to answer. He asked how big the gain in porosity is when making pellets instead of sinter. This, of course, depends to a great extent on the temperature to which the sinter or the pellets have been heated, and there is no adequate answer to this question. Hard-burned pellets have a nearly microscopical porosity of 20–25%, whilst hard-burned sinter has only macroscopical porosity. Light-burned sinter of the type used in Sweden has a high microscopical as well as a high macroscopical porosity. Light-burned pellets can be made with a porosity of over 30%, and the reducibility of such pellets is the same as that of light-burned sinter made from the same concentrate.

Theoretically porous pellets should have a better reducibility than light-burned sinter, as pellets made in shaft furnaces at a temperature that is not too high show a degree of oxidation of over 99½%, which means that the percentage of Fe_2O_3 counted on the total amount of oxide in the pellets is nearly 99%.

It is most important to keep the working temperature in the pelletizing furnace at an accurate level, and this temperature is above all dependent on the specifications for the product; it is, however, also dependent on the composition and other properties of the concentrates. If, as in the case of Malmberget, the pelletizing plant is placed at the mine and the product has to be shipped to distant places, it is necessary to make strong hard-burned pellets which can withstand handling without forming large quantities of fines. Such pellets must be burned at the highest possible temperature, especially if they are intended to be used as refining ore. For pellets intended for blast-furnace use a higher amount of fines is probably permissible, and so it would be possible to make less strong pellets with a higher porosity and a better reducibility. If the pelletizing plant is placed at the blast-furnace, whereby handling can be avoided, weaker pellets could be made with a high porosity and good reducibility.

As Dr. Wendeborn says, it is a great advantage to have found an agglomeration method that can be carried out at the mines, especially as in the Malmberget case the long hard winters make it almost impossible to transport concentrates in railroad cars to the ports.

Mr. Saniter is quite right in stating that the fuel cost of the Dwight-Lloyd and Greenawalt processes in the U.K. and many other countries is lower than in the oil- or gas-fired pelletizing furnaces. Coke breeze is cheap, especially in countries where great quantities of coke are produced. At Malmberget, however, the cost for 1·5% of fuel oil is comparable with the cost of about 5% of coke breeze. In a sintering plant of the standard Dwight-Lloyd or Greenawalt type the consumption of coke breeze when sintering the very fine Malmberget concentrates will probably not be lower than 7%. Thus,

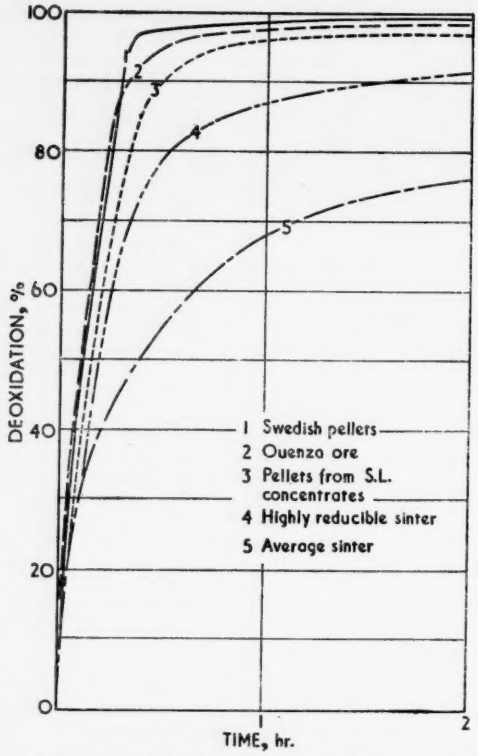


Fig. A—Comparison of reduction rates of various materials by hydrogen at 750° C.

in this case, a great saving in fuel cost will be achieved when using the shaft-furnace pelletizing method.

It is true that the pelletizing process, especially when performed in shaft furnaces, is a process of precision. The Swedish quality-steel industry, however, has never been afraid of using precision methods, if they make it possible to produce a high-quality product economically. It is very satisfactory for an engineer to succeed in steering clear of both Scylla and Charybdis.

Mr. Saniter is probably too optimistic when he says that rich magnetite ores can be converted into hematite in a sintering machine as well as in a shaft-furnace pelletizing equipment. The degree of oxidation of over 99½% has not hitherto been achieved in a sintering plant of the standard type, and I doubt whether it will be possible even with the new methods now tried in special machines, where rolled pellets are used as raw material.

Nothing has yet been published about the large-scale trials with different proportions of pellets made in U.S. blast-furnaces. As soon as the Malmberget plant comes into operation, however, such tests will be made and the results will also be published.

I agree entirely with Mr. Saniter's final conclusion that the availability of a variety of methods can only lead to further progress, as a result of the best method being selected for each particular set of circumstances. I regret that in my paper I did not more clearly state my opinion of the possibilities of the shaft-furnace pelletizing method. It will probably be limited to the treatment of certain types of ore and will be a useful complement to the old methods of the agglomeration of fine iron ores. It is quite possible that the shaft-furnace pelletizing method will never, or only to a small extent, be used in the U.K., where the local ores seem less suitable for this method, but I hope that large quantities of Swedish pellets will be imported to the U.K. to help to bring down the coke consumption in blast-furnaces.

Dr. Wendeborn's contribution to the discussion is of great value: being a prominent designer of sintering machines he must, of course, be optimistic about the development he is working on. He is right in stating that very good results have been achieved on the first large-scale sintering machine in Babbit and that the output is higher than 1000 tons/day. The production of the shaft furnace at Aurora, however, has been raised to 900 tons/day since my paper was presented. It is probable that this furnace will finally reach a production of 1200 tons/day or more. The limit set by Dr. Wendeborn of 350–500 tons/day is thus already considerably exceeded. The competition between the different new methods is extremely inspiring for the development of the agglomeration processes and will probably also result in improvements on the ordinary sintering machines for treating fines of coarser nature.

I should like to thank Mr. Sven Fornander for his kind remarks about the work done in Sweden.

Finally, I should like to correct some mistakes made in my paper. The proposed sintering machine at the Cleveland-Cliffs Iron Company at Ishpeming will be designed by the Sintering Machinery Corporation, Netcong, New Jersey, and not by the Koppers Company.

Mr. **Ridgion** wrote: In regard to Mr. Saniter's request for further information on reducibility, laboratory tests have been carried out on a variety of British sinters, and on sample pellets the pellets show more rapid reduction. Figure *A* shows a selection of curves for reduction by hydrogen at 750° C. Porosity figures using the S.K. tests are in line with these. We have not done similar tests on Swedish sinters which are of an unusually high degree of oxidation.

Mr. Uhrus's remarks on recuperation and on discrepancies between our estimates of fuel consumption and those attained in Sweden are valuable in that they serve to emphasize the extent of the difference in practice between using magnetite and hematite. Not only does magnetite provide useful heat of oxidation, but this fact also makes it possible to recover the sensible heat of the product as air preheat.

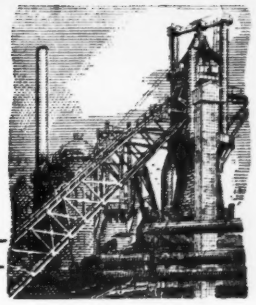
Mr. **Stirling** wrote: The sulphur problem at Corby will almost certainly become more serious in the future, but the vacuum-extrusion process of agglomeration, if it can be combined with a desulphurization firing, is attractive both technically and financially. Firing has not yet been taken beyond the laboratory stage and many difficulties will have to be overcome before one can hope to have simple vertical shaft furnaces firing and desulphurizing green pellets inexpensively.

The first of the two strategies mentioned by M. Astier is very attractive, and I agree with him fully that it is most important to distinguish in any ironmaking practice which of these two technical policies is being followed. In terms of the process described in the paper, the alternatives mentioned by M. Astier arise largely because a full-scale method for firing has not yet been evolved and, although there are few data for guidance, the economics of a high-temperature desulphurizing treatment may well compare favourably with the sintering process practised with the quality control now expected of the best operation.

The remarks of Dr. Wendeborn and of Mr. Ludwig are also welcome, and seem to encourage the further development of the vacuum-extrusion process.

IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP



Waste-Heat Recovery Related to the Generation of Electric Power

By W. Ernest, A.M.I.Mech.E.

SYNOPSIS

Modern developments in waste-heat boiler practice and increases in fuel prices encourage the recovery of heat from waste furnace gases. An attempt is made to investigate the economics and general features of generating electric power from waste-heat steam. A tentative enquiry is also made into the possibilities of using gas turbines for recovering the heat directly from furnace gases.

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WASTE-HEAT recovery has been of importance in steelworks operation for many years both in the form of heat returned to the furnace as preheat of air and fuel gas and in the utilization of hot gases for external purposes such as the generation of steam. Excellent surveys of the general subject have been made.[1, 2]

In particular, the use of waste-heat boilers and the generation of steam for works use has increased constantly, until today few O.H. furnaces are constructed without waste-heat boilers. Experience and improved designs and operating techniques have increased the efficiency of this form of waste-heat recovery. Amongst many papers describing boiler design and operation those by Cameron and Kilby[3] and McDonald[4] should be mentioned.

The most recent suggestions for improvement in design and operation of O.H. furnaces incorporate steam-producing elements in door frames and other parts of the furnace which are normally water-cooled.[5-7] These improvements presume the existence of waste-heat boilers and increase the amount of heat usefully converted into steam instead of allowing it to be dissipated into the atmosphere. Thus, the yield of steam per therm fired at the furnace is increased. This may be considered incidental to the main purpose of steam cooling, which is the saving of cooling water and improvement in the life of cooling elements.

In non-integrated plants making steel in O.H. furnaces from cold pig and scrap and rolling products in modern mills using electric motor drives, the installation of waste-heat boilers to the fullest extent might result in a steam-generating potential in excess of the steam demand of the works. In many instances, therefore, potentially useful heat is not recovered merely to satisfy temporary peak demands with plant having an inherently high installation cost per pound of steam produced.

Generally speaking, certain small potential sources of waste-heat steam are rarely tapped; these include soaking pits, forge furnaces, coke ovens, and other gas-producing plant.

This paper is an attempt to examine the question of utilizing surplus waste-heat steam for generating electric power to supply part of the works' load in parallel with the national supply or with the works'

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Mr. Ernest is in the Research and Development Department of the United Steel Companies Ltd.

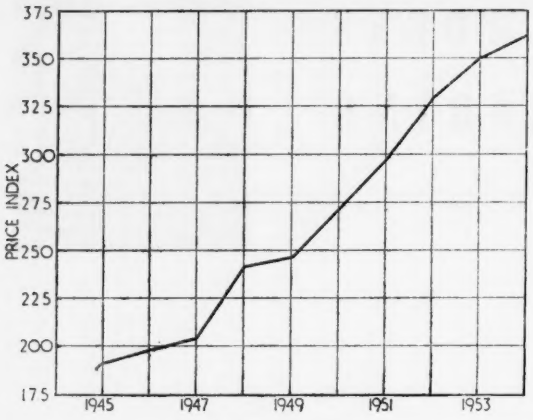

Fig. 1—Coal price index 1945–54

power station. With the exception of one or two instances where waste-heat steam is added to the main steam supply generated in fuel-fired boilers in integrated works, the practice of generating power from waste-heat steam is not common. There are some obvious attractions and equally obvious technical problems in such a concept but the main problems are economic, and must be fully investigated for individual circumstances. They will be influenced by the level of coal prices, to which electricity costs from the public supply are usually tied.

Figure 1 shows the price index of coal over the last ten years; although electricity costs have not risen in the same proportion (largely owing to the improvement in the national load factor), it is inevitable that a similar trend has been followed, thus making utilization of waste heat progressively more attractive.

Increased utilization of waste-heat sources must never be allowed to interfere with the prime function of producing, heating, and rolling the products of the works. For this reason, a scheme of generating power from surplus steam must be simple and not necessarily the most efficient which could be provided. Early protagonists of waste-heat boilers to some extent met the objection from steelplant managers that O.H. furnaces tended to be run as steam instead of steel producers. Today, most operators would agree that waste-heat boilers assist in furnace operation because of improved draught control; there seems to be no reason to expect that further conversion (to electric power) would interfere significantly with the operation of production plant.

POWER GENERATION FROM WASTE-HEAT STEAM

Obviously, there is considerable variation in individual cases, depending upon the output and products of a particular works. The calculations and conclusions are therefore based upon a medium-sized hypothetical steelworks having an ingot output of 10,000 tons per week from cold-charged fixed O.H. furnaces and producing a range of finished and semi-finished products.

Steam and Power Requirements

Table I gives estimated power and steam consumption figures for the various departments. The departmental outputs used for calculation purposes are given; although variations will exist in individual plants, the figures of unit power consumptions and steam demands are considered to be fairly representative.

The indicated power consumption represents an annual usage of 71 million units and a consumption per ingot ton of 142 units. The maximum kVA. demand, based on a 70% load factor and 0·85 power factor, would be about 14,000 kVA.

Figure 2 shows an estimated integrated time/electric-load curve and indicates the average power

Table I

ELECTRIC POWER AND STEAM CONSUMPTION FOR STEELWORKS

10,000 ingot tons per week capacity

Department	Throughput, tons/week	Power		Steam	
		Units per Ton, kWh.	Weekly Consumption, kWh.	Hourly Demand (av.), 1000 lb./hr.	Weekly Consumption, 1000 lb.
Melting shop	10,000	6	60,000	15·8	2630
Blooming mill	10,000	20	200,000	10·3	1400
Billet mill	8500	21	179,000		
Bar and section mill	3000	48	144,000	4·6	626
Hot strip mill	2000	56	112,000	3·6	490
Rod mill	3000	90	270,000	4·2	575
Cold strip mill and pickling	1000	40	40,000	3·8	486
Forge	500	...	...	5·4	673
Machine and maintenance shops	...		40,000	11·5	1690
Traction (incl. cranes)	...		140 000	...	
Lighting	...		45,000	...	
Others	...		190,000	8·8	1470
Total			1,420,000	68·0	10,040

demand. An integrated steam-demand curve is shown in Fig. 3, the lower curve representing summer and the upper curve winter demand. The latter will be used for subsequent calculations.

The variations in hourly steam demand will be of the order of $\pm$ 30% about the mean, and short-time peak demand will require that the installed steam-generating capacity must be approx. 50% above the mean demand.

Generating Capacity

Although by using forced-circulation boilers of the La Mont type steam pressures of 400 lb./sq. in. have been used in waste-heat boilers, the more normal type of fire-tube boiler in common use in Great Britain is limited to about 200 lb./sq. in., and steam pressures of 150–180 lb./sq. in. are commonly adopted. A steam pressure and temperature of 175 lb./sq. in. and 500° F. is fairly representative of U.K. practice and will be adopted in the calculations.

The steam-generating capacity using waste heat from the melting shop, soaking pits, and forge furnaces would be approximately as shown in Table II.

The output from O.H. furnace waste-heat boilers incorporating economizers and full use of steam cooling is conservatively rated at 15,000 lb./hr. per operating furnace (allowing for steam usage of auxiliaries and induced-draught fan power equivalent).

Clearly, the capacity of waste-heat boilers is constant and exceeds the maximum live-steam demand by 23,000 lb./hr. and the average demand by 57,000 lb./hr. Table III gives the maximum, minimum, and average surpluses available for power generation.

The average distribution of steam production and consumption is represented by the Sankey diagram in Fig. 4.

The steam consumption per unit generated in small turbo-alternators is approximately as shown in Fig. 5. Higher efficiencies are not to be expected in view of the variable loading imposed under the conditions envisaged.

The surplus of waste-heat steam available over and above that used for satisfying the steam demand will therefore allow the generation of an average of 3400 kW., fluctuating between 1300 and 4500 kW. according to steam demand. This power can be used at practically 100% load factor if operated in parallel with the public supply, as only on very rare occasions will the base load of the works drop below 3400 kW. Since, however, these occasions (mainly weekends) coincide with the maximum availability of steam for power generation, a load factor of 90% will be used.

On this basis it will be possible to generate about 514,000 kWh. per week from waste-heat steam after satisfying all steam demand. This represents about 36% of the total works consumption.

Table II

STEAM PRODUCTION IN WASTE-HEAT BOILERS

Department	Units Installed		Steam Production per Hour	Steam Production per Week
Melting shop	8 100-ton furnaces	Waste gas Cooling frames	77,000	
	8 boilers with economizers		28,000	
	7 furnaces in operation		105,000	17,600,000
Soaking pits	10 furnaces			
	2 boilers (1 to 5 pits)		15,000	1,900,000
Forge	4 batch furnaces			
	1 boiler		5,000	625,00
		Total	125,000	20,125,0000

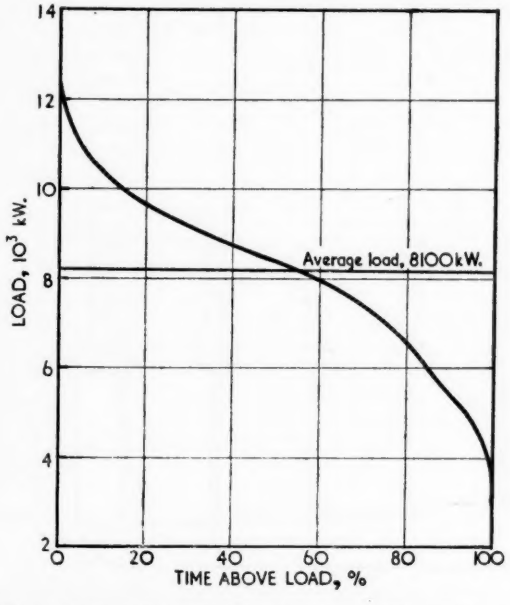

Fig. 2—Integrated time/electric-power-load curve

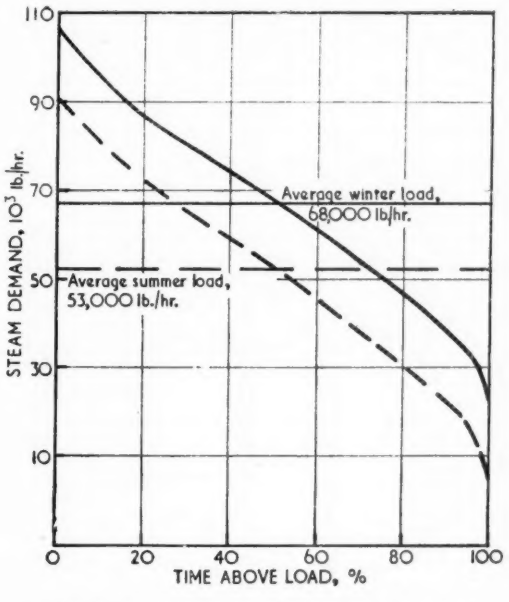

Fig. 3—Integrated time/steam-load curve

Table III
STEAM DEMAND AND SURPLUS

Supply, lb./hr.	Demand, lb./hr. Max.	Min.	Av.	Surplus, lb./hr. Max.	Min.	Av.
125,000	102,000	46,000	68,000	79,000	23,000	57,000

Capital and Operating Costs

The allocation of the share of capital cost of boilers and auxiliaries to be debited against power generation is difficult and depends very much on the individual point of view. Steam production from waste-heat boilers is constant and, to satisfy temporary peak demand without resorting to fuel-fired balancing boilers, capacity installed must be sufficient to cover these peaks. This may be worth while even though excess steam must be blown off to atmosphere. It may, therefore, be argued that if this steam is used for power generation neither capital nor operating costs should be borne by the power produced.

Similarly, introduction of steam cooling on O.H. furnaces amply recovers its capital cost on the basis of cooling-water savings only and the steam produced can be considered a by-product.

For the purpose of a general assessment it will initially be assumed that power generation is debited with capital and operating costs *pro rata* to the amount of power produced. This means that the works steam cost will be reduced and in any individual scheme it is the total cost of steam and power which must be balanced against existing conditions.

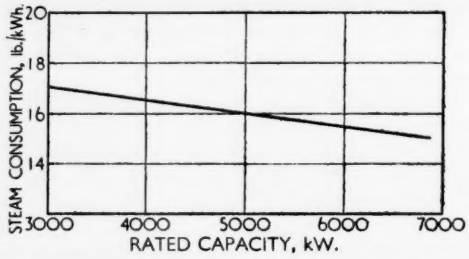

Fig. 5—Steam consumption of turbo-alternators

Capital costs of waste-heat boiler plant fully installed and serviced are about £2·5 per lb. of steam per hr. and this varies little, whether the steam is produced by the conventional boiler, by means of steam cooling of furnace parts, or by the addition of economizers to existing waste-heat boilers to increase their steam make.

The total capital cost per 1000 kW. installed capacity is approximately as shown in Table IV for installation of 4–8 MW. capacity.

Representative generating costs per unit produced will be approximately as shown in Table V.

Wherever the main power supply is taken from the British Electricity Authority, as in many steelworks, an important factor affecting the economics of home generation is the structure of the Authority's industrial tariffs. These tariffs vary in different parts of the country but a typical one is that used in the Yorkshire

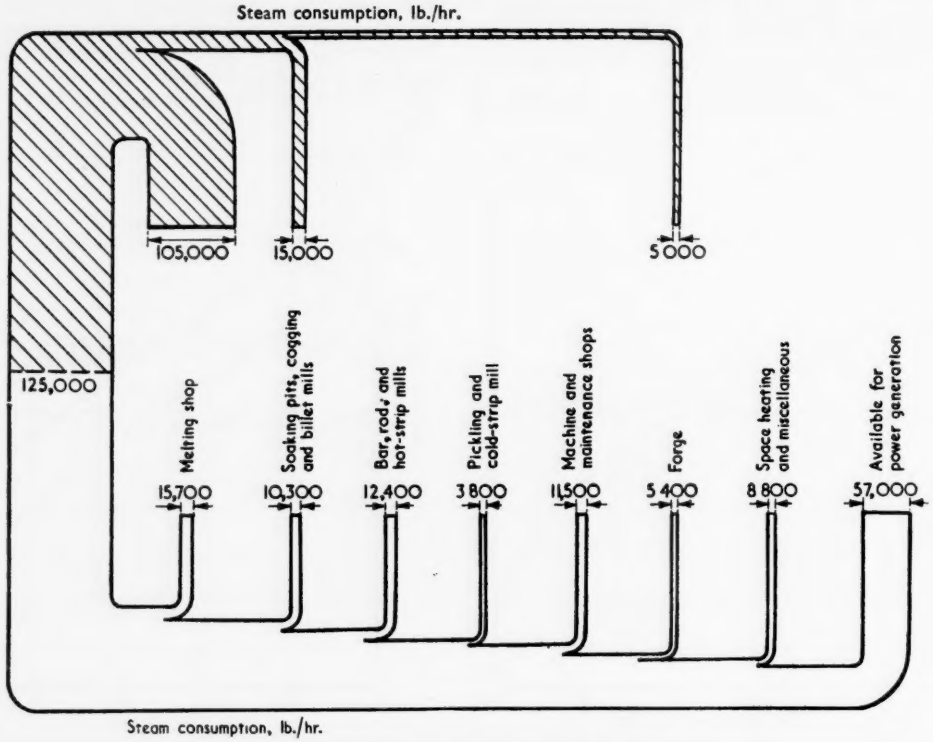

Fig. 4—Steam production and distribution

Table IV

CAPITAL COST OF POWER PLANT

	Cost per 1000 kW.
Boilers at £2·5 per lb. per hr.	£44,000
Turbo-alternator and electrics	£16,000
Buildings, steam piping, and services	£13,000
Cooling-water system	£5000
Total	£78,000

Area and detailed in the Appendix. This tariff includes the customary maximum demand charge and a running charge per kW. including a coal clause. At present a delivery price of 60*s.* per ton of coal to the power stations is representative and for the works under discussion the power cost, if all power is purchased externally, will be 0·824*d.* per unit.

The maximum demand for externally supplied power will not be reduced by the same proportion as the total number of units purchased, since it is an inherent feature of the scheme that the works generators should run at as high a load factor as possible, and the figure of 90% which has been assumed appears well within the bounds of possibility. The cost per unit purchased will therefore increase as the amount of home generation increases.

Figure 6 illustrates the general effect of this feature; it contains the following curves:

(*a*) The cost per unit generated at the works, which will vary slightly with size of installation owing to the increase of thermal efficiency with size. The figures in Table V are adjusted for size of installation

(*b*) The cost per residual unit purchased from the public supply for a total annual demand of 71 × 10^6 units and a maximum kVA. demand of 14,000 kVA. It is inherently assumed that the works generators carry a proportional part of the maximum demand

(*c*) The average unit cost, *i.e.*, a weighted average of (*a*) and (*b*).

An important point in judging the economics of any scheme of home power generation is the possibility of future increases in purchased power cost due to a rise in coal price. In the case of power generation from waste-heat boilers fuel price increases are irrelevant, since the fuel has to be burnt in the furnace in any case, and therefore a comparatively small increase in purchased power cost will affect the works significantly.

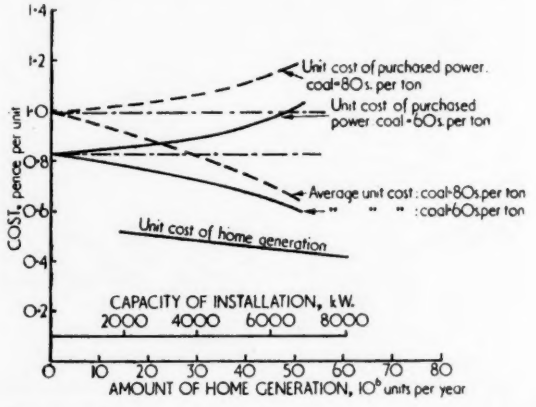
1·4
1·2
1·0
0·8
0·6
0·4
0·2
COST, pence per unit
Unit cost of purchased power. coal=80s. per ton
Unit cost of purchased power. coal=60s. per ton
Average unit cost: coal=80s. per ton
" " " : coal=60s. per ton
Unit cost of home generation
CAPACITY OF INSTALLATION, kW.
2000 4000 6000 8000
0 10 20 30 40 50 60 70 80
AMOUNT OF HOME GENERATION, 10^6 units per year

Fig. 6—Effect of works generation on unit power cost

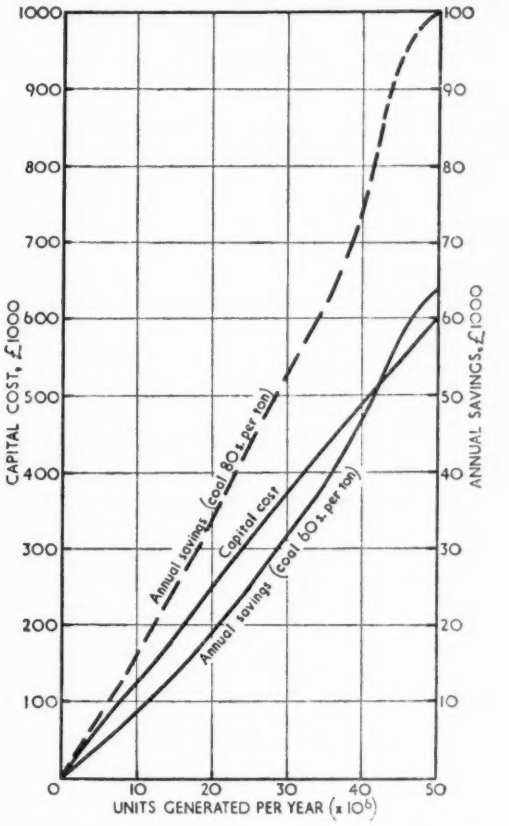

Fig. 7—Capital costs and savings for various levels of power generation

As an indication of the effect of this feature the broken curves in Fig. 6 indicate the calculated cost for purchased power based on a coal price of 80*s.* per ton delivered to power stations.

The net saving to the works is the difference between average unit cost and unit cost when the total consumption is drawn from the public supply, multiplied

Table V

UNIT COST OF POWER PRODUCED FROM WASTE-HEAT SYSTEM

Item	4000 kW. Installed Capacity at 100% Load Factor	Cost per kW Produced
Steam		
Labour	5*d.* per 1000 lb.	
Feed water	5*d.* " " "	
Power for I.D. fan	5*d.* " " "	
Depreciation	4*d.* " " "	
Maintenance	4*d.* " " "	0·35*d.*
Alternators		
Operating labour	1 man per shift	
Maintenance	£3000 per year	0·06*d.*
Depreciation	5%	
Condenser cooling water	0·75*d.* per 1000 gal.	0·07*d.*
	Total	0·48*d.*

Table VI

COMPARATIVE COSTS FOR WASTE-HEAT RECOVERY SCHEMES

Case	Total Installation Cost	Annual Steam and Power Bill	Difference Compared with Case (i)	Return on Capital, %
(i) No waste-heat boilers	...	£394,000*	...	....
(ii) Waste-heat boiler capacity 102,000 lb./hr.	£255,000	£328,000	£66,000	26
(iii) Waste-heat boiler capacity 125,000 lb./hr. Generating capacity installed 4000 kW.	£448,000	£268,000	£126,000	28

* Steam from coal-fired boilers at 6s. per 1000 lb.

by the total consumption. This is shown in Fig. 7 in relation to capital costs for the two coal price levels considered.

So far, it has been assumed that the electric power generated from waste-heat steam is debited with proportional capital and operating charges. It has already been stated that the overall economics are more favourable than indicated in Figs. 6 and 7, since surplus steam is utilized instead of being blown off. Table VI attempts to picture the overall steam and power costs for the works under discussion for three possible arrangements:

(i) No waste-heat boilers

(ii) Waste-heat boilers to satisfy the peak steam demand

(iii) Maximum waste-heat recovery including power generation.

Case (ii) might, for instance, be realized if waste-heat boilers together with steam cooling are installed on O.H. furnaces only, or if there is no steam cooling and boilers are installed on the reheating furnaces.

The figures of Table VI are based on current power costs, and no account is taken of cooling-water savings and other advantages due to steam cooling.

Back-Pressure Turbines and Auxiliary Firing

The foregoing considerations have been based on the use of normal fully condensing turbines and the independent use of steam at boiler pressure for process and other purposes for which low-pressure steam would be adequate.

In theory, increased overall efficiency and lower capital cost together with the elimination of condenser cooling water might result from the use of back-pressure turbines, the exhaust steam being used as process steam. Although desirable, it is doubtful if the increase in efficiency would compensate for the simplicity of the independent system and the necessity of duplicating steam supply mains for two processes. The possibility should, however, be considered in individual applications and especially where the process heating load is a large proportion of the total steam load, a state of affairs unlikely to arise in bulk steel production.

The addition of auxiliary firing of waste-heat boilers might overcome certain problems associated with the load diversity. Peak power demands occurring during a period of steam shortage seriously affect power costs and could be flattened by boosting temporarily the steam supply. Similar considerations also apply to waste-heat boilers supplying only steam in order to limit the installation cost.

INTEGRATED PLANT

So far, the discussion has been confined to cold-metal shops, but even in integrated steelworks, where by-product gases are normally used for generating steam and electricity, utilization of waste-heat steam may prove attractive in some instances.

The factors which must be considered, in addition to those appertaining to cold-metal plant, include coke-oven and blast-furnace gas balances together with standby fuels and are too complex to be submitted to the general analysis attempted in this paper.

Fuel distribution in integrated plant is already complex and has been given considerable attention and it may seem doubtful whether normally accepted methods of using coke-oven gas for steelmaking furnaces and blast-furnace gas for reheating furnaces and power plant can be improved in practice.

Nevertheless, several possibilities exist for further utilization of waste heat from steelmaking and re-

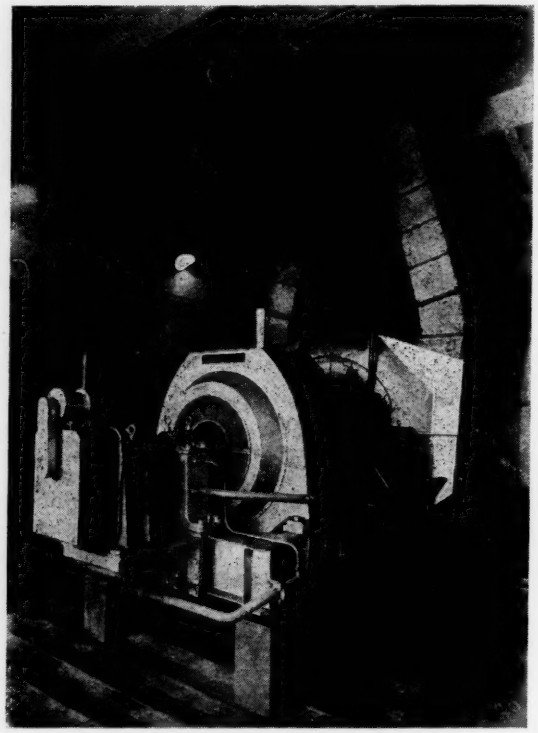

Fig. 8—1000-kW. industrial gas-turbine alternator

heating furnaces and the incorporation of waste-heat steam into the general power-supply system.[8]

Steam quantities will naturally be less per ton of steel produced in view of the reduced thermal input. Furthermore, in works producing steel from home ores it is already difficult at times to utilize effectively all the blast-furnace gas arising, although at other times gas shortages have to be made up by using standby solid or liquid fuels. It may be possible to eliminate to a large degree the use of standby fuels and also the use of coke-oven gas for steam production. Such surplus gas may then be used either to augment or replace liquid fuels in the melting shop, or to increase supplies to outside consumers.

The planning of B.E.A. base-load power stations in the vicinity of large integrated steelworks merits consideration; such stations might use the blast-furnace gas released by the use of waste-heat boilers to replace coal. This practice is followed in one or two instances on the Continent[9] and presupposes that the power plant is located very close to the steelworks to keep expensive mains down to the minimum. To make such a scheme economically attractive blast-furnace gas would have to be sold at a price lower than its thermal equivalent in coal, but an overall advantage might accrue, although the technical and economical factors are extremely complicated.

GAS TURBINES

So far, the only serious consideration given to the use of gas turbines in iron and steel works is for blast-furnace blowing.

It is interesting, however, to consider gas turbines

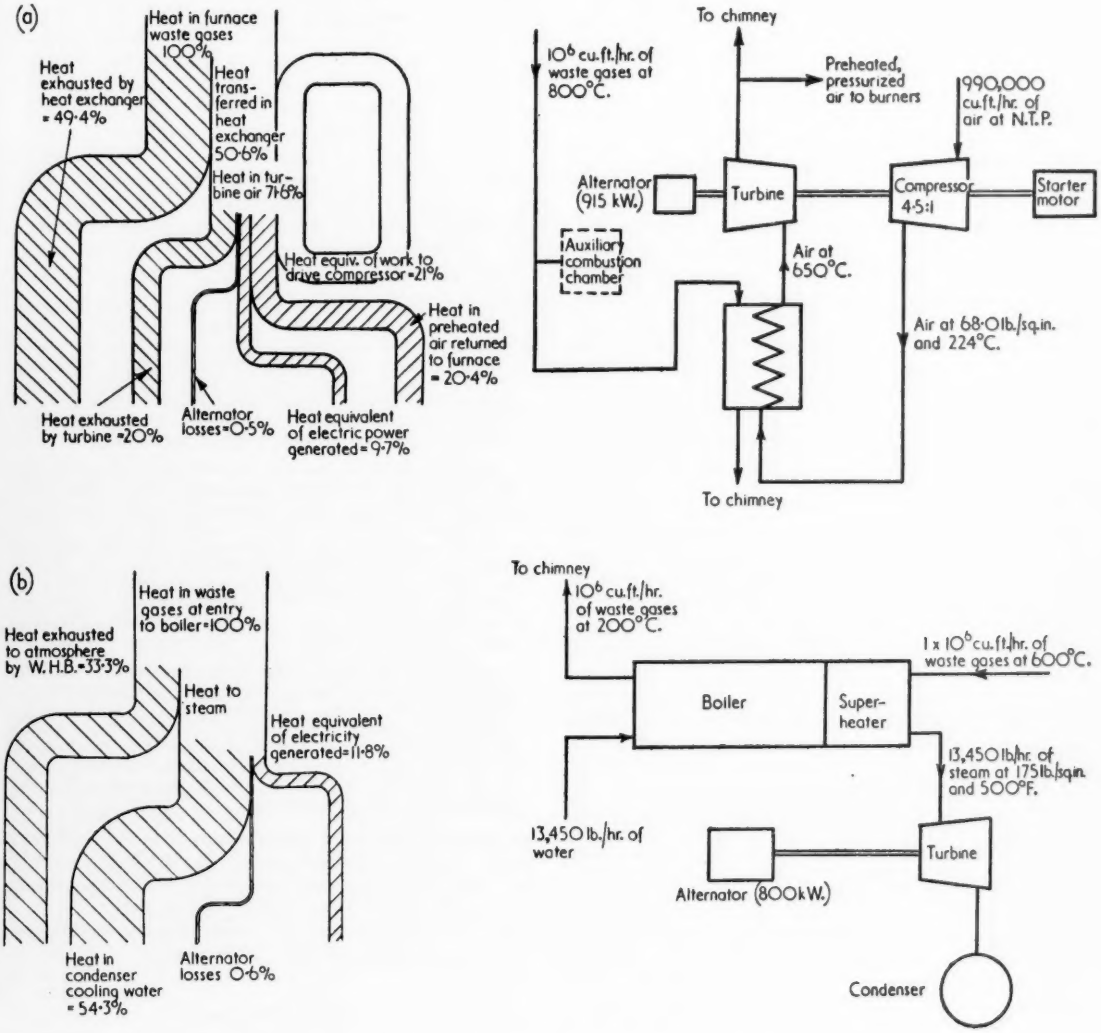
(a)
Heat in furnace waste gases 100%
Heat exhausted by heat exchanger = 49·4%
Heat transferred in heat exchanger 50·6%
Heat in turbine air 7·6%
Heat equiv. of work to drive compressor = 21%
Heat in preheated air returned to furnace = 20·4%
Heat exhausted by turbine = 20%
Alternator losses = 0·5%
Heat equivalent of electric power generated = 9·7%
To chimney
10⁶ cu.ft./hr. of waste gases at 800°C.
Preheated, pressurized air to burners
990,000 cu.ft./hr. of air at N.T.P.
Alternator (915 kW.)
Turbine
Compressor 4·5:1
Starter motor
Auxiliary combustion chamber
Air at 650°C.
Air at 68·0 lb./sq.in. and 224°C.
To chimney
(b)
Heat in waste gases at entry to boiler = 100%
Heat exhausted to atmosphere by W.H.B. = 33·3%
Heat to steam
Heat equivalent of electricity generated = 11·8%
Heat in condenser cooling water = 54·3%
Alternator losses 0·6%
To chimney
10⁶ cu.ft./hr. of waste gases at 200°C.
1 x 10⁶ cu.ft./hr. of waste gases at 600°C.
Boiler
Super-heater
13,450 lb./hr. of steam at 175 lb./sq.in. and 500°F.
13,450 lb./hr. of water
Turbine
Alternator (800 kW.)
Condenser

Fig 9—Comparison of (*a*) gas and (*b*) steam turbine cycles

in conjunction with hot waste gases emerging from industrial furnaces, although serious technical problems remain to be solved because of the inherently dirty nature of such gases. Gas turbines for this purpose would therefore have to use air as the working medium and might be of the closed- or open-cycle type. Because of space problems an extremely compact design would be necessary and Fig. 8 shows an example of a possible design which is, however, being developed for purposes other than waste-heat recovery.

One example of a gas turbine making use of waste gases from vertical retorts is installed at the Foleshill works of the Gas Board and has been described by Gregson.[10] This plant makes use of a waste-heat boiler to extract residual heat from the waste gases leaving the exchanger and the steam generated is used for process purposes. For steelplant operation the combined gas-turbine/waste-heat boiler system is not so attractive as in gasworks applications, since

(i) The temperature of waste gases from the furnace fluctuates considerably

(ii) The need to provide a waste-heat boiler in addition to the gas-turbine installation leads to space difficulties and high capital cost

(iii) Process steam demand is not constant.

To merit consideration for the recovery of heat from metallurgical furnaces a gas turbine must be self-contained and must avoid the necessity of an additional boiler. To achieve this object, the residual heat in the turbine exhaust air might be returned directly to the furnace from which the waste gases emerge in the form of preheated combustion air.[11] The advantages of this procedure would largely consist in having available combustion air at a limited amount of preheat (say, about 400° C.) and at a pressure of about 1–1½ lb./sq. in. This may be advantageous in promoting efficient combustion in high-temperature processes such as steelmaking furnaces.

Another possible cycle which avoids the auxiliary waste-heat boiler involves the use of a two-stage heat exchanger, the first stage of which extracts the residual heat in the turbine exhaust air. The waste gases from the furnace superheat the turbine air. No direct heat return to the furnace is involved but the cycle efficiency must be low if conventional regenerative furnaces are involved.

Figure 9*a* shows a somewhat speculative cycle diagram and heat balance for a gas-turbine installation applied to an O.H. furnace, in which part of the turbine exhaust air is returned to the furnace as combustion air. Since the air inlet temperature to the regenerators would be about 400° C. the waste-gas outlet temperature from the regenerators might be about 800° C. instead of the more customary 575–625° C. This would give a turbine inlet temperature of 650° C.

The thermal efficiency of the system is greater than that of the more conventional boiler/steam-turbine system shown for comparison in Fig. 9*b*. The difference is not great and installation costs may play the decisive part, together with floor-space requirements and the importance of the cooling-water problem.

Considerable problems still remain to be solved in the design and maintenance of such a turbine (mainly in the heat exchanger) but these should not be any more severe than those which, for instance, arise in gas turbines using pulverized coal or peat and which are already in an advanced stage of development.

These ideas are put forward purely as possible future developments in furnace operation; no evidence yet exists of the practicability of gas turbines working in conjunction with hot waste gases.

ELECTRICAL PLANT

For home power generation to be an effective economic proposition, parallel operation with the public supply is essential in order to take advantage of the base load and a high inherent load factor. In some ways this might be considered to reflect adversely on the operations of the British Electricity Authority, but the imposition of maximum demand charges adequately covers the reduction in the load factor of externally purchased power. In principle, the British Electricity Authority has agreed to the utilization of back-pressure sets in industrial undertakings in parallel with the public supply, a procedure comparable with that discussed in the paper.

Clearly, adequate precautions have to be taken for safe and successful operation although these are well established. For the comparatively small amounts of power which can be generated by using surplus waste-heat steam the three main possibilities of generating equipment are:

(i) *Synchronous Generators*—Adequate synchronizing equipment has to be installed, but where high-voltage generators are used which are operated as 3-phase, 3-wire machines, little difficulty should be experienced.

If the generator is of appreciable capacity in comparison with the total network capacity some automatic voltage regulation may be required to keep the system voltage within the necessary statutory limits

(ii) *Asynchronous Generators*—These appear to be the best prospect as they are simple to operate and require less supervisory labour than synchronous generators.

Since normally the magnetizing current will be supplied from the external network, it may be necessary to install power-factor correction equipment (*e.g.*, synchronous motors). The disadvantage of asynchronous generators is that the failure of the external supply would also cause the works supply to fail

(iii) *D.C. Generators*—These cannot be operated in parallel with the B.E.A. supply (assuming that this is A.C.) but might be an economical proposition for installation where a fairly constant D.C. load exists in the works, as conversion losses can be eliminated. Since these conversion losses might amount to about 10%, the potential losses due to reduction in load factor might be outweighed.

In normal waste-heat installations it is unlikely that power will be available for export to the public supply and this eliminates problems which sometimes occur where private generating plant is installed.

In all cases, however, the protection of switchgear will require approval by the Authority.

CONCLUSIONS

At the present time and in the foreseeable future it appears inevitable that recovery of heat from waste

gases in the form of steam will be an inherent feature of furnace operation. Steam requirements, especially of cold-metal plants, are less than could be produced by conventional waste-heat boilers applied to all usable sources.

This position is intensified by the recent development of forced-circulation cooling of O.H. furnace parts by saturated steam/water mixtures, the cooled parts being placed in circuit with the boilers.

To make full use of all waste heat arising in economical quantities, generation of electric power seems to be the most practicable proposition and an attempt is made in this paper to investigate some of the problems which would accompany such a concept as related to a medium-sized O.H. steelplant.

The main problem is one of economics, and the tendency of coal (and oil) prices may make the generation of waste-heat power progressively more attractive.

Only general points can be dealt with in this paper and individual assessment for production plant may in many cases give answers substantially different to those arrived at in the paper. It is nevertheless suggested that the method of assessment adopted is reasonable and that similar calculations for individual works might be worth while as a background for future action. Almost certainly the results of such a survey would be of interest in themselves and might lead to various improvements without extensive additional plant installation.

Although integrated plants do not lend themselves to easy investigation, even there more extensive recovery of steam from metallurgical furnaces and its use for supplementing the normal blast-furnace gas fired steam system may prove attractive, as already proved by its adoption in one or two works.

Brief reference is made to gas turbines; however, their flexibility is inferior and only incorporation into the furnace system as a whole, thereby reaping some possible advantages in furnace performance, will make them attractive for waste-heat recovery in their present state of development.

Acknowledgments

The author wishes to thank Mr. F. H. Saniter, Director of Research, United Steel Companies, Ltd., for permission to publish this paper. He is indebted to colleagues in the Research and Development Department and the works of the United Steel Companies, Ltd., for help with data, criticism, and suggestions and, in particular, to Mr. A. C. Robinson for carrying out many of the calculations.

Figure 8 is reproduced by courtesy of W. H. Allen Sons and Co., Ltd., Bedford.

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APPENDIX

Extract from the Industrial Tariff of the Yorkshire Electricity Board

Two-part Tariff for the Larger Consumer

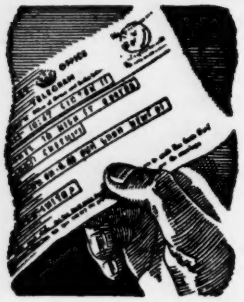
Available to all consumers taking industrial supplies and having an estimated maximum demand not less than 5 kVA. The tariff is:

	High-Voltage Supplies						Low-Voltage Supplies					
	Annual Demand Charge			Monthly Demand Charge			Annual Demand Charge			Monthly Demand Charge		
	£	s.	d.	s.	d.		£	s.	d.	s.	d.	
Demand Charge												
For each of the first 100 kVA. of annual maximum demand	4	7	6	8	9		4	12	6	9	3	
For each of the next 150 kVA. of annual maximum demand	4	2	6	8	3		4	7	6	8	9	
For each of the next 250 kVA. of annual maximum demand	3	17	6	7	9		4	2	6	8	3	
Excess	3	15	0	7	6		4	0	0	8	0	

	High-Voltage Supplies (above 650 V.)	Low-Voltage Supplies
Unit Charge		
For each of the first 250 units supplied in any month per kVA. of maximum demand in that month	0·675*d.*	0·725*d.*
For each of the next 100 units supplied in any month per kVA. of maximum demand in that month	0·625*d.*	0·675*d.*
Excess	0·575*d.*	0·625*d.*

Fuel Adjustment—The payment in respect of each month shall be subject to an addition or reduction at the rate of 0·0007*d.* in the case of high-voltage supplies and 0·00075*d.* in the case of low-voltage supplies per unit supplied in that month for each penny by which the fuel cost per ton used for the purpose of and shown on the invoice for the supply of electricity in bulk by the British Electricity Authority to the Board in the previous month is more or less than 60*s.* 0*d.* per ton.

'*Maximum Demand*' means in respect of each year, or month, of account as the case may be, the highest demand recorded in that year, or month, by the demand indicator or indicators provided by the Board.



NEWS

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Annual General Meeting, 1955

The **Annual General Meeting** of The Iron and Steel Institute will be held at 4 Grosvenor Gardens, London, S.W.1, on **Wednesday and Thursday, 27th and 28th April, 1955.** The Dinner for Members will be held at Grosvenor House, Park Lane, on Wednesday, 27th April.

Full details of the programme will be given in a later issue of the *Journal.*

Special Reports

Brickwork of Blown-Out Blast-Furnaces

A recent addition to the series of Special Reports published by The Iron and Steel Institute is a report entitled "*A Survey of the Results of the Examination of the Brickwork of Blown-Out Blast Furnaces,*" prepared by the British Ceramic Research Association, under the guidance of the Blast Furnace Refractories Joint Committee of the British Iron and Steel Research Association and the British Ceramic Research Association.

This survey gives data on 79 blown-out furnaces at 30 plants that have been examined during the last 20 years, and includes a discussion on the causes of the deterioration of blast-furnace brickwork. Copies of the Report (No. 51 in the Series) are available from the offices of the Institute, price 25*s.*, post free (15*s.* to Members).

Ingot Moulds Sub-Committee

The latest addition to the Series is the "*Third Report of the Ingot Moulds Sub-Committee,*" prepared by a sub-committee of the British Iron and Steel Research Association. This report brings up to date the work of the Ingot Moulds Sub-Committee on ingot-mould performance, and discusses the results of the practical application of recommendations made in the Sub-Committee's earlier reports.

Part I considers the relationship of mould performance to the conditions of service encountered in the steelworks. In Part II the chemical composition of the mould iron is discussed and the effects of silicon, phosphorus, manganese, sulphur, and carbon are considered. The properties and conditions of the mould iron are dealt with in Part III, and factors of mould design are considered in Part IV.

Based on much study and experiment, the Sub-Committee has drawn up recommended principles of mould design, which are given in detail in an Appendix. Other Appendixes give progress reports of the Foundry Techniques Group and the Large Moulds Group, and an indication of current mould consumptions in the U.K.

The Report, No. 52 in the Series, is fully illustrated with diagrams and photographs, and is bound in cloth with stiff board covers. It is obtainable by Members of the Institute at 15*s.* per copy, post free (non-Members 25*s.*).

Bibliography on Rolling

Bibliography No. 15*a*, "*The Rolling of Iron and Steel*" is now available; it is an extension of No. 15, which covered the period 1920–1947, and it includes abstracts and references to text books published up to early in 1954. The subjects dealt with include the theory of rolling, descriptions of rolling-mill plant, roll-pass design, the manufacture of rolls, the effect of rolling on the properties of iron and steel, etc. As in the earlier Bibliography, there is a section on the manufacture of seamless tubes. The price to Members is 15*s.* (non-Members 25*s.*).

NEWS OF MEMBERS

▶ Dr. H. H. BURTON has been made a Director of the English Steel Forge and Engineering Corporation Ltd.

▶ Mr. G. BUTTERWORTH has been awarded the degree of M.A.(Cantab.), and has been made an Associate of the Institution of Metallurgists.

▶ Mr. D. CATHCART has been appointed Manager of the Armour Department at the Parkhead Steelworks of Wm. Beardmore and Co., Ltd.

▶ Mr. J. F. G. CONDÉ has left The Mond Nickel Co., Ltd., to join the Admiralty Gunnery Establishment, Southwell, Dorset, as Senior Scientific Officer.

▶ Mr. P. M. COWPER-COLES has been appointed Managing Director of Telektron (Great Britain) Ltd.

▶ Dr. C. J. DADSWELL, a Director of the English Steel Corporation Ltd, has been appointed Managing Director of the subsidiaries, the English Steel Castings Corporation Ltd., and the English Steel Spring Corporation Ltd. He has also been made a Director of the English Steel Forge and Engineering Corporation Ltd.

▶ Capt. H. LEIGHTON DAVIES, C.B.E., Past-President of The Iron and Steel Institute and Assistant Managing Director of the Steel Company of Wales Ltd., has been appointed Chairman of the Welsh Board for Industry.

▶ Mr. B. S. EKELUND has transferred from Söderfors Bruk to the headquarters of Stora Kopparbergs Bergslags AB, Falun, Sweden, where he has been appointed Technical Intelligence Officer.

▶ Mrs. U. J. C. ENDE has left B.I.S.R.A. to become Information Officer in the Plant Department of British Oxygen Engineering Ltd.

▶ Mr. E. M. FENN has left the Chemistry Department of B.I.S.R.A. to join the staff of Murex Ltd.

▶ Mr. A. GRIEVE has left the Ironmaking Division of B.I.S.R.A. to take charge of the research laboratory of the Eastern Mining and Metals Co. in Singapore.

▶ Mr. O. J. HINETT has joined Renold Chains Ltd., Coventry.

▶ Mr. D. H. Houseman has been awarded the degree of Ph.D. of the University of Cambridge, and has been elected to the W. J. Rees Research Fellowship in refractory materials at the University of Sheffield.

▶ Mr. R. A. Lake has been appointed Chief Engineer at the Redbourn Works of Richard Thomas and Baldwins Ltd.

▶ Mr. G. F. Lilly has joined the Research Department of the International Nickel Company of Canada.

▶ Mr. T. McGarrity has left the Research Department of Hadfields Ltd. to join the metallurgical staff of the Singer Manufacturing Co., Ltd.

▶ Dr. V. A. Phillips has left the British Non-Ferrous Metals Research Association to take up the appointment of Senior Metallurgist in the Chemical and Metallurgical Section of the English Electric Co., Ltd., Luton Airport.

▶ Mr. F. Pickworth has been appointed Chairman of the following five subsidiary companies of the English Steel Corporation Ltd.: English Steel Forge and Engineering Corporation Ltd., English Steel Rolling Mills Corporation Ltd., English Steel Castings Corporation Ltd., English Steel Spring Corporation Ltd., English Steel Tool Corporation Ltd.

▶ Mr. W. D. Pugh, Assistant Managing Director of the English Steel Corporation Ltd., has been appointed Managing Director of the subsidiary, the English Steel Forge and Engineering Corporation Ltd. Mr. G. Gilfillan, Special Director of the English Steel Corporation, has been appointed a Director. Mr. Pugh will also serve on the Boards of the English Steel Rolling Mills Corporation Ltd., English Steel Castings Corporation Ltd., and English Steel Spring Corporation Ltd.

▶ Maj.-Gen. E. P. Readman has been appointed Managing Director of the English Steel Tool Corporation Ltd., a subsidiary of the English Steel Corporation Ltd.

▶ Mr. J. A. Reavell, Chairman of the Kestner group of Companies, is at present paying a visit to South Africa and Southern Rhodesia.

▶ Mr. C. W. Ridge has been appointed Managing Director of F. Issels and Son, Ltd., Bulawayo, S. Rhodesia.

▶ Mr. R. T. Rolfe, O.B.E., has retired from his appointment as Chief Metallurgist to W. H. Allen, Sons and Co., Ltd. He is succeeded by Mr. J. R. Bryant, formerly Deputy Chief Metallurgist. Mr. Rolfe will remain associated with the Company in a consultative capacity.

▶ Dr. R. J. Sarjant, O.B.E., has been appointed Director of Research of the British Steel Castings Research Association, and Dr. A. H. Sully, formerly Head of the Metallurgy Division of the Fulmer Research Institute, has been appointed Associate Director of Research.

▶ Mr. R. F. Summers, Chairman of John Summers and Sons Ltd., and a Director of The United Steel Companies Ltd., has been appointed a member of the London Midland Area Board of the British Transport Commission.

▶ Mr. R. G. H. Taylor, a Director of the English Steel Corporation Ltd., has been appointed Managing Director of its subsidiary, the English Steel Rolling Mills Corporation Ltd., and Deputy Chairman of the English Steel Tool Corporation Ltd.

▶ Mr. Joseph Walton has retired from the Joint Managing Directorship of Thos. W. Ward Ltd. He will remain connected with the Company in a consultative capacity and will also retain his position as Chairman and Managing Director of the Darlington Railway Plant and Foundry Co., Ltd.

▶ Dr. P. A. Young has resigned the Elmore Research Fellowship in Extraction Metallurgy at the University of Cambridge, and has joined the Development Department of the Imperial Smelting Corporation, Avonmouth.

Obituary

Mr. Norman Burton, of Norman Burton and Brother, Knutsford, in May, 1954.

Mr. H. D. Cottam, Managing Director of Edwin Cottam and Co., Ltd., Rotherham, on 3rd November, 1954.

Mr. R. H. Dimmock, of Llanelly, in September, 1954, aged 46.

Mr. E. W. Elcock, of Sheffield, on 29th December, 1954.

CONTRIBUTORS TO THE JOURNAL

P. M. Cook, B.Sc., A.Inst.P., A.I.M.—Senior Investigator in charge of Forging Research in the Mechanical Working Division of B.I.S.R.A.

P. M. Cook

Mr. Cook was born in London in 1920. He was awarded the external degree of B.Sc. of London University in 1943, following part-time studies at Sheffield and Rotherham Technical Colleges. He received industrial training with Kayser Ellison and Co., Ltd., from 1936 to 1945, and then spent two years in the Physics Department of the Brown-Firth Research Laboratories. He took up his present appointment in 1947.

M. G. Gemmill—In charge of the High-Temperature Metals Section in the Swinden Laboratories of The United Steel Companies, Ltd.

Mr. Gemmill received his metallurgical education at the Royal Technical College, Glasgow. He has been with The United Steel Companies, Ltd., since 1945, apart from one year spent studying high-temperature materials in the U.K., Europe, Canada, and the U.S.A., under the auspices of a Mond Nickel Fellowship. He took up his present appointment in 1952.

J. A. Kerr, B.Met.—On the staff of the Research Department of William Jessop and Sons, Ltd., Sheffield.

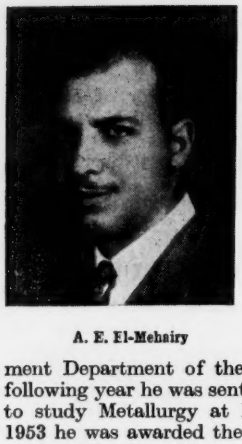
Mr. Kerr was born in 1925. He received his technical education at the University of Sheffield, where he was awarded the degree of B. Met. in 1949. He took up his present appointment in the same year.

David Smith, B.Sc., Ph.D.—Lecturer in Fuel Technology at the University of Sheffield.

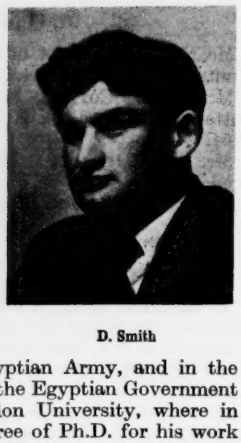
Dr. Smith was educated at the Grammar School, Burton-on-Trent, and at the University of Sheffield, where he graduated in physics in 1948. He carried out post-graduate research on heat transfer in continuous reheating furnaces in the Department of Fuel Technology, and in 1952 was awarded the degree of Ph.D. He was appointed to the University staff in 1950. In 1953 Dr. Smith spent five months studying in the Department of Chemical Engineering, Massachusetts Institute of Technology, under Professor H. C. Hottel, and visiting fuel and steel industries in the North East of the United States.

A. E. El-Mehairy, B.Sc., Ph.D., A.I.M.—Research Metallurgist in the Department of Mineral Resources, Ministry of Commerce and Industry, Cairo.

Dr. El-Mehairy was born in Egypt in 1928. He graduated from Cairo University with 1st Class Honours in Chemical Engineering in 1948. In the same year he was appointed First Lieutenant in the Research and Develop-



A. E. El-Mehairy



D. Smith

ment Department of the Egyptian Army, and in the following year he was sent by the Egyptian Government to study Metallurgy at London University, where in 1953 he was awarded the degree of Ph.D. for his work on the reduction of iron ores. He then spent a year in the iron and steel industry of the Ruhr, Germany, before returning to Egypt to take up his present appointment. He has since been engaged on the establishment of Metallurgy Research Laboratories of a Mineral Research Centre in Cairo and on research into the reduction of iron ores.

IRON AND STEEL ENGINEERS GROUP

The **Twenty-Eighth Meeting** of the Iron and Steel Engineers Group will be held at the offices of the Institution of Electrical Engineers, Savoy Place, London, W.C.2, on **23rd March, 1955.** A Buffet Luncheon will be arranged in the Tea Room of the Institution.

The following is the programme:

10.30 A.M.–12.45 P.M.—Presentation and discussion of: "*Some Comments on Waste-Heat Recovery Practice*," by W. Gregson (Spencer-Bonecourt Ltd.)

12.45–2.0 P.M.—Buffet luncheon (tickets 4*s.* 6*d.*)

2.0–4.0 P.M.—Presentation and discussion of: "*Waste-Heat Recovery Related to the Generation of Electric Power*," by W. Ernest (United Steel Companies Ltd.) (*see* this issue, pp. 271–279).

INSTITUTE OF METALS

Sir William H. White

At an interesting ceremony that took place at 4 Grosvenor Gardens, London, S.W.1, on 25th January, a portrait of Sir William H. White, F.R.S., Founder President of the Institute of Metals, was presented by Dr. R. W. Bailey, F.R.S., President of the Institution of Mechanical Engineers, to Dr. S. F. Dorey, C.B.E., F.R.S., President of the Institute of Metals.

Dr. Bailey referred briefly to the founding of the Institute of Metals and to the close connections that had been maintained between the two societies. Dr. Dorey, in thanking the President and Council of the Institution for their generous gesture, remarked on the interesting coincidence that he had followed in Sir William White's footsteps very closely by becoming successively President of the Institution of Marine Engineers, the Institution of Mechanical Engineers, and the Institute of Metals, and that he too had received his early training in a naval dockyard.

Dr. Maurice Cook seconded the vote of thanks and said that the engineers who were the founders of the Institute had shown a remarkable foresight in setting up a society to cover the then almost unknown field of non-ferrous metallurgy.

The portrait, which is on permanent loan, hangs in the Council Room of the Institute.

NEWS OF SCIENCE AND INDUSTRY

Research Fellowship

Applications are invited for the T.I. Research Fellowship tenable in the Department of Metallurgy of the University of Sheffield. The object of the Fellowship is to advance knowledge in the field of Metallurgy; candidates should already have some research experience, but not necessarily in this field. Normal tenure will be five years, but the appointment will be for two years in the first instance and thereafter will be renewable annually. The stipend is £750 per annum for the first year, rising by annual increments of £50 to £950 per annum, together with superannuation provision under the F.S.S.U. A higher stipend may be paid to an exceptional candidate. Applications (3 copies) including the names and addresses of referees and, if desired, copies of testimonials, should reach the Registrar (from whom further particulars may be obtained) not later than 31st March, 1955.

Special Courses at Leeds University

A short course of two lectures will be given on "*Disposal of Waste Liquors Produced in Gas Works and Coke Ovens*," at the University of Leeds on 14th March, 1955. A course of four lectures on metallurgy will also be held at the beginning of March; details have not yet been arranged. Inquiries should be addressed to the Head of the Department of Coal Gas and Fuel Industries with Metallurgy, The University, Leeds, 2.

Spring Conferences at University of Birmingham

The annual Spring Conferences in the Department of Industrial Metallurgy at the University of Birmingham will be held on 14th–15th March, 1955. The subject for the first day will be "*Graphitization in Cast Irons*," and for the second day "*The Structure and Properties of Electrodeposited Metals and Alloys*." Applications for admission to both Conferences should be made to the Secretary, Department of Industrial Metallurgy, The University, Birmingham, 15, from whom full particulars of the programme may be obtained.

Suspension of Steel Import Duties

After consultation with the Iron and Steel Board, H.M. Government has decided to make a new Order affecting the temporary suspension of import duties on iron and steel. The Order prolongs the temporary suspension of import duty on cold-rolled steel sheets of a value of less than £80 per ton until March 18th, 1956, and suspends until September 18th, 1955, the import duties on a wide range of iron and steel products.

The new Order, known as the Import Duties (Exemptions) (No. 1) Order 1955 (SI.33), came into operation on 14th January. Copies may be obtained from H.M.S.O. or from any bookseller, price 3*d.*

Tonnage Oxygen

The increase in recent years in requirements for tonnage oxygen in iron- and steelplants and in gas separation plants has led the British Oxygen Co., Ltd., to combine with Gesellschaft für Linde's Eismachinen A.G. to form a joint company to handle their plant sales business in the fields of air and gas separation.

Hitherto, in the U.K., tonnage oxygen has been supplied by pipeline from B.O.C. plants. This facility will continue, but the new Company, to be known as British Oxygen Linde Ltd., will offer to industry air separation plants, including tonnage oxygen and nitrogen plants,

of the most advanced types, backed by a unique fund of resources in design and production. Gas separation plants for coke oven gas, refinery gases, etc., will also be included, and the Company's range of products extends to the complete engineering of schemes and the installation of units ready to operate.

British Oxygen Linde Ltd. will operate in the U.K. and in other parts of the world where it will co-operate with associate overseas companies of the B.O.C. group. The Board of the Company consists of Mr. F. J. Clark and Dr. P. H. Sykes of the B.O.C., together with two directors of the German company.

Ore-Handling Plant

A new ore-handling plant is to be installed at the Clyde Iron Works of Colvilles Ltd. The plant, which will have a capacity of 500 tons/hr., will include a 950-ft. long conveyor which will run parallel with the stockyard and will deliver the ore to a second conveyor 700 ft. long, which will in turn deliver to an ore-screening station. So that ore may be diverted to a possible future crushing plant, a reversible belt feeder will be sited at the junction of the two conveyors. The plant, including motors and control gear, will be constructed by the General Electric Co., Ltd.

Working Model Steelworks

A working model of a complete steelworks has been lent to the Science Museum, South Kensington, by the British Iron and Steel Federation. Occupying a total floor area of 60 ft. × 24 ft., the model is on a scale of 6 ft. to 1 in., and represents a steelworks covering a site of over ¼ sq. mile and having a weekly capacity of 10,000 tons. The model demonstrates clearly the various processes from the iron ore to the finished product, and shows ancillary equipment including 1500 pieces of rolling stock and 20 locomotives.

A selection of recent films on various aspects of the iron and steel industry is being shown in conjunction with the exhibition of the model.

Wild-Barfield Electric Furnaces Ltd.

The induction heating business of Wickman Ltd. has been acquired by Wild-Barfield Electric Furnaces Ltd. The manufacture of plant is to continue at Oxgate Lane, Cricklewood, for the present, until it is transferred to the Wild-Barfield works at Watford.

Soaking Pits

An order for a battery of 12 soaking pits worth about £500,000, has been received by Stein and Atkinson Ltd. The pits, which are for the Lackenby beam mill of Dorman Long (Steel) Ltd., will be of the one-way-fired type and will have Austeel-Escher recuperators for pre-heating both the air and the blast-furnace gas.

CORRIGENDA

Reduction of Iron Oxides by Solid Coke

In the synopsis of the paper by Dr. B. G. Baldwin, published in the January, 1955, issue, p. 30, the fifth line should read "... coke to give two molecules of CO ..." and not CO_2, as printed.

News of Members

It was incorrectly stated in the December, 1954, issue of the *Journal*, p. 397, that Dr. N. H. Polakowski had left La Salle Steel Co., Chicago, to join the Department of Metallurgical Engineering, Illinois Institute of Technology. Dr. Polakowski is still with La Salle Steel Co., and his association with the Illinois Institute of Technology is on a part-time basis only.

DIARY

1st Mar.—Sheffield Metallurgical Association—"*Segregation in High-Speed and Other Tool Steels*," by E. Johnson—B.I.S.R.A., Hoyle Street, Sheffield, 3, 7.0 p.m.

3rd Mar.—Institute of Metals (Birmingham Local Section)—"*Recent Developments in Stainless Steels*," by J. I. Morley—James Watt Memorial Institute, Great Charles Street, Birmingham, 6.30 p.m.

4th Mar.—West of Scotland Iron and Steel Institute (Joint meeting with the Iron and Steel Engineers Group)—"*Engineering Aspects of Heavy Section Mills*," by T. Walker—39, Elmbank Crescent, Glasgow, C.2.

7th Mar.—Cleveland Institution of Engineers—"*Steelworks Waste-Heat Boiler Practice*," by R. McDonald—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 6.30 p.m.

9th Mar.—North Wales Metallurgical Society (Joint meeting with the Liverpool Metallurgical Society)—"*Siliceous Refractories*," by G. R. Rigby—County Primary School, Plymouth Street, Shotton, 7.15 p.m.

10th Mar.—Liverpool Metallurgical Society—"*Tube Manufacture*," by E. Davis—Liverpool Engineering Society, The Temple, Dale Street, Liverpool, 7.0 p.m.

10th Mar.—Staffordshire Iron and Steel Institute—"*The Future of Steel Melting*," by M. W. Thring—Station Hotel, Dudley, 7.30 p.m.

18th Mar.—West of Scotland Iron and Steel Institute—"*Current Trends and Developments in the Use of Creep-Resisting Steels in Steam Power Plant*," by M. G. Gemmill—39 Elmbank Crescent, Glasgow, C.2.

21st Mar.—Sheffield Society of Engineers and Metallurgists—"*Protection of Steel Works from Atmospheric Corrosion*," by F. R. Himsworth—University Buildings, St. George's Square, Sheffield, 7.30 p.m.

24th Mar.—Staffordshire Iron and Steel Institute—"*Quality Control in Steel Works*," by N. H. Bacon—Station Hotel, Dudley, 7.30 p.m.

26th Mar.—Swansea and District Metallurgical Society—"*Continuous Casting*," by J. Savage—Central Library, Swansea, 6.30 p.m.

29th Mar.—Staffordshire Iron and Steel Institute (Associates' Section)—Annual General Meeting—Wednesbury Technical College.

29th Mar.—Sheffield Metallurgical Association—"*The Mechanism of the Action of Boron in Low Alloy Steels*," by F. B. Pickering—B.I.S.R.A., Hoyle Street, Sheffield, 3, 7.0 p.m.

1st Apr.—Ebbw Vale Metallurgical Society—Annual Dinner.

2nd Apr.—Swansea and District Metallurgical Society—Annual Dinner.

4th Apr.—Cleveland Institution of Engineers—"*The Development of Ore Handling at the West Hartlepool Works of the South Durham Steel and Iron Co., Ltd.*," by S. H. Walker—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 6.30 p.m.

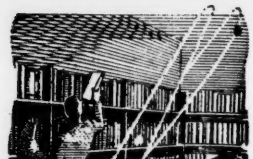
TRANSLATION SERVICE

(The previous announcement was made in the February, 1955, issue of the *Journal*, p. 180).

Translation in Course of Preparation

(German). A. Schack: "Flow Conditions and Heat Balance in Modern Soaking Pits." (*Stahl und Eisen*, 1954, vol. 74, Nov. 4, pp. 1502–1507).

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES



IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

French Iron Mines. (*Usine Nouvelle*, 1954, Spring Issue, 17–27). In 1952, production of iron ore in France (40·7 million tons) was second only to production in the U.S.A. (95·6 million tons), and iron ore was the most valuable export. Reserves in France exceed those in U.S.A. Data are given for the Lorraine basin, the western basin, and the Pyrenees basin, with discussion on the importance of the Lorraine basin. Algerian, Tunisian, Moroccan, and French West African ore beds are also briefly described. Sections are included on methods of exploitation, blasting, mechanical loading, transport, crushing, and safety in the mines. Production has been multiplied by 2·5 since 1945.—T. E. D.

Notes on Some Iron Ore Deposits in Algeria. (*Echo Mines*, 1954, May, 297–298; June, 375–378). A short account of the geological formation of Algerian iron ore deposits, and the methods used for the mining and transport of the ore, is given.—B. G. B.

Chrome Ore Mining in Turkey. H. F. Kromer. (*Eng. Min. J.*, 1954, **155,** Aprl., 92–95). Since 1945, economic conditions have led to increased exploration and higher exports of chrome ore. Private capital is needed to develop the industry. A survey is made of the known deposits, mining methods and costs, and the financial and legal aspects of mining operations.—K. E. J.

Outlook for Jamaica : Mining Upswing. H. S. Strouth. (*Min. Eng.*, 1954, **6,** July, 699–700). An iron ore concession has been granted to a company associated with Standard Ore & Alloys Corp. of New York. Hematite and magnetite orebodies low in phosphorus, silica, and sulphur, averaging 64% Fe have been outlined; a monthly production of about 25,000 tons is planned. Reserves are estimated at over 1 million tons, and trial shipments are planned for early 1955.—K. E. J.

Manganese Resources of India—Their Conservation and Utilization. J. C. Ghosh and T. C. Bagchi. (*Eastern Metals Rev.*, 1953, **6,** Feb. 2, 145–148). The development of manganese deposits in India and the steps taken by the government to conserve them are discussed.—B. G. B.

ORES—MINING AND TREATMENT

Mining Development and Engineering in Quebec. J. P. Drolet. (*Eng. J.*, 1954, **37,** July, 809–819). A comprehensive review, with geological and physical maps, is given of the mineral resources of Quebec, and of the major projects of the last five years dealing with iron ore, ilmenite, copper ore, and asbestos.—K. E. J.

Research on the Cutting Action of the Diamond Drill Bit. E. P. Pfleider and R. L. Blake. (*Trans. Amer. Inst. Min. Met. Eng.*, 1953, **196,** 187–195).

The Selection of Detachable Drill Bits. E. R. Borcherdt. (*Trans. Amer. Inst. Min. Met. Eng.*, 1953, **196,** 201–208).

Orientation of Cube Diamonds in Drill Bits. E. P. Pfleider. (*Trans. Amer. Inst. Min. Met. Eng.*, 1953, **196,** 998–1003).

Recent Developments in Mining and Metallurgy in Australia. N. R. Srinivasan. (*Eastern Metal Rev.*, 1953, **6,** Feb. 2, 61–70). A short survey of the major developments in Australia is given.—B. G. B.

Sinter Is What You Make It. E. H. Rose and D. J. Reed. (*J. Met.*, 1954, **6,** June, 740–744). The authors report progress of research undertaken by the Tennessee Coal and Iron Division (United States Steel Corp.) to establish quality criteria and control for iron ore sinter produced in the central ore conditioning plant. Emphasis is given to the novel features of instrumentation of the sinter plant developed to attain a reasonable degree of success; they include a magnetic permeability meter, stack gas analysis, recording pyrometer, draught gauges, water addition flowmeter, and ignition gas flowmeter.—G. F.

Taconite Beneficiation Comes of Age at Reserve's Babbitt Plant. O. Lee. *J. Met.*, 1954, **61,** June, 737–739). A summary is given of the methods of beneficiation of taconite ore at the Babbitt plant, Minnesota, of the Reserve Mining Co. Particular attention is given to the concentrating and pelletizing plants, which are based mainly on results obtained by the Mines Experimental Station of the University of Minnesota. A brief outline is also given of possible future operations.—G. F.

The Beneficiation and Agglomeration of Taconite at the Babbitt Works (Minnesota, U.S.A.). (*Génie Civil*, 1954, **131,** Aug. 15, 313–314). An outline is given of the Reserve Mining Co. plant in the Mesabi Range. The taconite is drilled for blasting by jet-piercing, and, after blasting, is transported about 2 miles to the crusher in 22-ton lorries. The ore is crushed, and ground in rod mills and finally by ball mills to 80–85% − 325 mesh. Power consumption for grinding is about 11 kWh./ton. About 1000 tons/day of (64·5% Fe) concentrates were produced by magnetic concentration from taconite containing 28% Fe as magnetite, with 90% recovery. The concentrate is pelletized with 10–25% water and about 8 lb. of bentonite per ton as binder, in drums about 6½ ft. in dia. and 15 ft. long, rotating at 15 r.p.m. The ½–1 in. pellets are fed to four rectangular kilns heated by 1½ gall./ton of oil in addition to 1% of anthracite added per ton before pelletizing. The firing temperature is between 1260–1290° C.,

and the pellets are discharged at the bottom of the kiln at about 95° C., fully oxidized to hematite. This plant is the start of a project for a plant to produce 10 million tons of concentrates per year.—T. E. D.

Taconite Progress Recalls Edison Experiments at Ogden Mine. (*Min. Eng.*, 1954, **6**, July, 672–673). An historical note describes the work of T. A. Edison at Ogden mine, where a system of magnetic separation was devised for upgrading ore of 20% iron content. Conveyor belts were first adapted for ore handling, then improved to resist abrasion. Operations were curtailed by discoveries on the Mesabi range.

How to Select Synchronous Motors for Taconite Grinding Mills. J. C. Marous and E. F. Merrill. (*Eng. Min. J.*, 1954, **155**, July, 84–87).

Mills for Pulverising Minerals. N. P. Waganoff. (*Tecn. Industr.*, 1954, **32**, Apr., 299–302). [In Spanish]. Descriptions and drawings are given of pan mills, centrifugal mills, pendulum roller mills, ring roller mills, and ball mills.

The Beneficiation of the Low Grade Manganese Ores of Orissa. P. K. Ghosh, M. K. De, and R. B. Ghosh. (*Eastern Metals Rev.*, 1953, **6**, May 18, 536–539; May 25, 559–560). In the course of the detailed mapping and field study of the manganese ore belt of this district in India, a collection of low grade samples of ores were collected. The results of laboratory trials carried out on the upgrading of the ores are described.—B. G. B.

Recovery of Manganese from Low-Grade Ores. L. N. Allen, jun. (*Chem. Eng. Prog.*, 1954, **50**, Jan., 9–13). A process developed by the Chemical Construction Corp. is described in which 20·2%-Mn concentrates are reacted in a slurry with SO_2 and oxygen in an autoclave at about 600 lb./sq. in. and 450° F. to convert the MnO_2 in the ore to soluble $MnSO_4$. The solution is evaporated and the $MnSO_4$ is sintered to MnO_2, and the SO_2 produced is recycled to the leaching step. Laboratory test results are given and are used as a basis for estimating the economics of a plant to produce up to 303 tons/day of manganese as a 60%-Mn sintered product from the 20·2%-Mn concentrate.—T. E. D.

Differential Flotation of Pyrites and Pyrrhotite. G. T. Lindroth. (*Tekn. Tidskr.*, 1954, **84**, June 29, 603–605). [In Swedish]. A description is given of the physical structure of pyrrhotite, it being stated that its unpredictable behaviour during flotation is due to changes in surface and flotation characteristics resulting from its varying crystallographic structure.—G. G. K.

Operating Behavior of Liquid-Solid Cyclones. E. B. Fitch and E. C. Johnson. (*Trans. Amer. Inst. Min. Met. Eng.*, 1953, **196**, 304–308).

The Application of Centrifugal Forces to Gravitational Classifiers. R. C. Emmett and D. A. Dahlstrom. (*Trans. Amer. Inst. Min. Met. Eng.*, 1953, **196**, 1015–1021).

Study on the Oxidizing-Roasting of Kamaishi and Takanokura Iron Ores. S. Sasaki and H. Adachi. (*Tetsu to Hagane*, 1952, **38**, Apr. 175–181). [In Japanese]. These studies, made with the object of determining the degree of oxidation of the iron, and the possibilities of desulphurizing or improving reducibility by roasting, included chemical and mineralogical examinations, and observations of the changes caused by roasting.—K. E. J.

A Study on Synthetic Fayalite. S. Sasaki and H. Adachi. (*Tetsu to Hagane*, 1952, **38**, Mar., 138–143). [In Japanese]. Synthetic fayalite was made by the reduction of Fe_2O_3 mixed with quartz sand, and could be crystallized to form lath, pillar, or polyhedral shapes. When the heating temperature was above the FeO-SiO_2 liquidus line, a glassy form was obtained. In the sintering of ore-coke briquettes at 1000–1105° C., a peculiar structure indicating the formation of wüstite and metallic iron was recognised.—K. E. J.

How to Control Heat for Calciners. W. G. Bauer. (*Chem. Eng.*, 1954, **61**, May, 193–200). A general discussion of calciners, in which heat is generated externally or, by combustion, internally, is presented. Rotary and shaft kilns are included. The effect of flame pattern on radiation profile is shown diagrammatically.—T. E. D.

FUEL—PREPARATION, PROPERTIES, AND USES

The Storing of Coal in America so as to Prevent Spontaneous Ignition. W. Franke. (*Glückauf*, 1954, **90**, July 31, 853–856). After outlining the causes of spontaneous ignition of coal, the author describes methods used in America for storing coal to prevent ignition.—L. D. H.

Rate of Carbon-Dioxide/Carbon Reactions in Deep Fuel Beds. M. W. Thring and P. H. Price. (*Iron Coal Trades Rev.*, 1954, **169**, Aug. 6, 347–349). The authors discuss the relationship between physical and chemical factors in determining the rate of carbon-dioxide/carbon reactions in deep fuel beds. In particular they examine how far the reaction rates observed by Nicholls can be explained by extrapolation of the chemical reaction rates of Gadsby, using the diffusion rates determined from heat transfer measurements.—G. F.

Utilization of Waste Heat in the Metal Industry. M. Havelka. (*Hutnik*, (Prague), 1954, **4**, (6), 166–171). [In Czech]. The sources of waste heat in the production of coke, in steelmaking, rolling, forging, and ironmaking are discussed and the actual and potential possibilities of utilizing this heat are considered.—P. F.

Waste-Heat Recovery Related to the Generation of Electric Power. W. Ernest. (*J. Iron Steel Inst.*, 1955, **179**, Mar., 271–279). [This issue].

Refractory Recuperators. F. H. Cass, N. L. Franklin, and A. L. Roberts. (*J. Inst. Fuel*, 1954, **27**, June, 319–325). The principles of metallic and ceramic recuperators are noted, and mathematical treatment is given to exit temperature distribution in a cross counterflow system. Several possible variations in design are dealt with, and factors affecting gas flow within the recuperator discussed. Suggestions for desirable trends in design and application are made.—D. L. C. P.

Practical Uses of Steel Recuperators in Metallurgical Furnaces. J. Faure. (*Mét. Constr. Mécan.*, 1954, **86**, Apr., 327–335; May, 421–431; June, 517–525). The design and operation of several different types of ceramic and metallic recuperators are discussed. The advantages of the metallic type of recuperator are considered and the design of recuperators of cast iron and of steel construction are described. Diagrams and photographs of metallic recuperators are shown.

Reflections on the Project for the International Classification of Coals. H. Cassan. (*Chaleur et Ind.*, 1954, **35**, Aug., 222–230). Present national classifications and the proposed international classification of coals are discussed, and some suggestions are made as a result of the author's own experience.

Communication on the Evaluation of Washing Trials with Bituminous Coal. O. Schäfer. (*Glückauf*, 1954, **90**, Aug. 14, 908–917). An analysis of the results of washing trials carried out to compare methods and plant, and to investigate possibilities of quality control is given.—L. D. H.

Second International Congress on Coal Preparation. (*Glückauf*, 1954, **90**, Sept. 25, 1213–1316). This issue of *Glückauf* reports the proceedings at the Second International Congress on Coal Preparation held at Essen on Sept. 20–25, 1954. Among the papers presented were:

Effect of Wetting Coal to Reduce Dust in Colliery Operations on the Screening During Preparation. K. Thein. (1231–1242).

Classification of Unscreened Coal in a Schüchtermann & Kremer-Baum AG. Drum Classifier at the Haus Aden Mine. H. Paul. (1250–1257).

Preparation of Coal Fines in High, Medium, and Low Pressure Cyclones. E. Hoffmann. (1262–1268).

The Separation of Fine Middlings in the Belt Sink Classifier. S.-R. Schönmüller. (1268–1276).

The Heavy-Medium Preparation of the Fine and Finest Grains in the Centrifugal Separator. R. Teuteberg. (1276–1282).

New Possibilities with Static Dewatering. K. Lemke. (1283–1288).

A New Wet Mechanical Process of Reducing the Ash Content of Very Fine Raw Coal. W. Gründer. (1288–1291).

Classifying and Dewatering Slimes by the Convertol Process. K. Lemke. (1291–1296).

Properties and Economic Significance of the Raw Material in Coal Preparation. J.-R. Schönmüller. (1299–1307).

New Guides to the Supervision of Coal Preparation Plants. G. A. H. Meyer. (1307–1309).

Comments on the Determination of Yield in Coal Preparation Processes. C. Kühn. (*Z.V.d.I.*, 1954, **96**, Aug. 1, 739–746). The authors investigations lead to the conclusion that the Paul error triangles are to be preferred to partition curves in the estimation of inaccuracies in coal cleaning processes, as the calculation of the organic yield is thereby simplified.—J. G. W.

Carbonizing Properties of American Coals: Index of Coals Tested by the Bureau of Mines. R. L. Brown, J. D. Davis, D. A. Reynolds, and F. W. Smith. (*U.S. Bureau of Mines*, 1954, Bull. 536).

Experimental Study, in the Laboratory, of the Pressures Developed by Coals During Carbonization. J. François and R. Bedier. (*Chaleur et Ind.*, 1954, **35**, July, 205–212). No absolutely certain laboratory test exists for determining whether a given coal will be dangerous for use in a coke oven. An attempt is made to obtain a test in which the isothermal surfaces of coking in the sample are not curved, as in the Koppers test, and the method is described in detail. Results on three coals tested at varying initial pressures are shown graphically and are discussed.—T. E. D.

On the Representation of the Plasticity of Molten Coals. J. H. Granval. (*Chaleur et Ind.*, 1954, **35**, July, 198–204). A new method of graphical representation of the melting phenomena occurring when bituminous coals are heated is put forward.—T. E. D.

The Experimental Station at Marienau in 1953. R. Loison. (*Rev. Ind. Min.*, 1954, **35**, June, 561–583). The work of the station during 1953 may be classified in three groups: (*a*) Studies on coal blends under normal coking conditions, including the use of dry charges; (*b*) the influence of coking conditions and blending; and (*c*) the investigation of new methods for the production of semi-coke for which a semi-plant-scale fluidization apparatus has been built. Results achieved in these projects are reported.—A. G.

Low-Temperature Carbonization Assay of Coal in a Precision Laboratory Apparatus. J. B. Goodman, M. Gomez, V. F. Parry, and W. S. Landers. (*U.S. Bureau of Mines*, 1953, *Bull.* 530).

A Study on the Coke-Oven Operation. S. Haseba and M. Nakahara. (*Tetsu to Hagane*, 1952, **38**, Mar., 111–114). [In Japanese]. It has been pointed out that lengths of coke-oven life of 25–30 years in the U.S.A. are assisted by the high collecting main pressure. A description is given of preliminary trials and actual working of Kukioka No. 1 oven with a pressure of 6 mm. W.G.—K. E. J.

Application of Low-Temperature Carbonization. R. E. Zinn. (*Chem. Eng. Prog.*, 1954, **50**, Jan., 3–8). The development of low temperature carbonization techniques is discussed with examples. These include brief outlines, with diagrams, of the Disco and Hayes indirect heating processes, and the Lurgi-Spülgas, National Fuels Corporation, Parry, and Singh direct heating processes. The advantage of not using temperatures much higher than 500° C. is emphasized, and the uses of the products are mentioned.—T. E. D.

Two-Stage Coal-Gas Producer—Controlled Gasification and Distillation. (*Engineering*, 1954, **178**, July 16, 90–91). This article describes a 2-stage gas producer with two off-takes, the lower one taking away a quantity of gas before it can reach the distillation zone. By varying the amount of gas taken by the lower off-take, the amount passing to the distillation and drying zones can be controlled to give the ideal rate and temperature required for the distillation of the volatiles. The two stages of gas production, gasification and distillation, are thus separated and, at the same time, brought under control.—M. D. J. B.

Trials on the Gasification of Pulverized Coal by the Panindco Process. R. Loison and H. Gautier. (*Rev. Ind. Min.*, 1954, **35**, June, 529–560). After a description of the pilot plant installation at Rouen the trials made during 1953 are reported. Pulverized coal and preheated air are delivered into the top of the gas producer through two concentric jets at 10–20 m./sec. Lower down, steam is injected to solidify the ash which is removed through a water seal. With a high volatile coal, gas with a calorific value of 1100 calories is obtained using air. With oxygen, or air plus oxygen, Fischer or synthesis gas can be produced.—A. G.

Gasholders: Special Application in the Steel Industry. T. H. Riley. (Cleveland Tech. Inst.: *Iron Steel*, 1954, **27**, Aug., 399–402). The author describes the four main types of modern gasholder which have applications in the steel industry. They are the spiral guided water-sealed holder, the M.A.N. waterless holder, the Klonne dry-sealed holder, and the Wiggins fabric-sealed holder.—G. F.

TEMPERATURE MEASUREMENT AND CONTROL

Objective (Photoelectric) Optical Pyrometer. A. M. Gurevich. (*Zavodskaya Laboratoriya*, 1950, **16**, (11), 1336–1341). [In Russian]. The photoelectric optical pyrometer described is designed for use in controlling temperature when rolling metal. The normal temperature range of the instrument is 800–1300° C. A narrow wavelength band (0·6–0·7μ) is used, enabling the sensitivity and accuracy of a visual pyrometer to be combined with objectivity of readings and possibility of recording. Optical and circuit diagrams are given and the performance under exacting industrial conditions is compared with other types of instrument.—S. K.

Improved Work in Foundries as a Result of Temperature Measurements with an Imersion Pyrometer. J. Stejspal. (*Slévárenství*, 1954, **2**, (6), 170–173). [In Czech]. An immersion pyrometer of recent Czechoslovak construction is described and compared with a similar instrument of British manufacture.—P. F.

REFRACTORY MATERIALS

At the Crook Works of Pickford, Holland & Co. Ltd. (*Refract. J.*, 1954, **30**, July, 294–302). An illustrated description of the newly equipped works is given. Products are silica and basic refractories in many different shapes and sizes.—D. L. C. P.

Basic Bessemer Steelworks—The Dolomite Plant. A. Richard. (*IRSID, Centre d'Etudes supérieures de la Sidérurgie*, Metz, 1953, "*Les Cahier du CESSID*" No. V). The required qualities and characteristics of the raw materials, dolomite and tar are stated. The general layout of a dolomite plant is described with a brief note on the equipment it contains. The fundamental operations involved in the preparation of mixtures for bricks and converter bottoms are outlined with an account of recent developments such as vibrated bottoms and magnesia tuyeres. Finally the factors of economy and labour are considered and trends in the construction of modern dolomite plants are discussed.—A. G.

Carbon in the Engineering and Metallurgical Industries. V. S. Kingswood. (*Metallurgia*, 1953, **48**, Aug., 55–62; Sept., 133–135; Oct., 169–174; Nov., 221–227; Dec., 301–305). An historical survey of the industrial use of carbon is first presented, and the structure of the various allotropes of carbon is discussed. Details are given of the raw materials from which industrial carbons are made and of the processes used in their production. The use of carbon for blast-furnace linings is described and the development of carbon electrodes for arc furnaces, electrolytic production of non-ferrous metals, and welding is considered. The production of hard-metal carbides and the application of carbon to foundry and heat-treatment processes are reviewed.—B. G. B.

Silicon Carbide, Its Manufacture and Uses in the Refractory Industry. M. Maire. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1954, (5), 927–932). After an account of the synthesis of silicon carbide in 1891, its industrial manufacture is described. Its properties of extreme hardness, high melting point and good conductivity are exploited in special refractory ware with 87% and 50% silicon carbide. Uses, including furnace burners, vertical zone retorts, and pyrometer tubes, are mentioned.—A. G.

The Determination of Grain Size and Its Importance in the Ceramic Industries. (*Ceramics*, 1954, **6**, June, 156–160). The methods outlined are: Sedimentation, rapid hydrometer, light absorption, gas diffusion, Schone's elutriator, and the Andreasen pipette.—D. L. C. P.

Some Studies of Mullite Formation. A. J. Shorter. (*Refract. J.*, 1954, **36**, June, 246–248). A brief account is given of attempts to promote the union of corundum with clays to form mullite. It was shown that few chemical promoters had any significant beneficial effect.—D. L. C. P.

Activation Energies for the Decomposition of Limestone, Dolomitic Limestone and Dolomite. J. H. Wernick. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **199**: *Min. Eng.*, 1954, **6**, July, 730–732). There appears to be a change in the rate-controlling processes, the break-up of the carbonate ion being predominant below 880° C., and the diffusion of cations and $O^=$ ions above this temperature. The type of atmosphere can also affect the decomposition rate, as a result of fundamental interactions between the bonding situation at the carbonate surface and the molecules of the atmosphere.

Differential Thermal Analysis Methods and Techniques. J. A. Pask and M. F. Warner. (*Amer. Ceram. Soc. Bull.*, 1954, **33**, June, 168–175). The requirements of a differential thermal analysis apparatus are set out, and the type developed and used at the University of California for research on the

thermal reactions occurring in refractory materials is described.—D. L. C. P.

Note on the Relationship Between Bulk Density and Thermal Conductivity in Refractory Insulating Bricks. K. W. Cowling, A. Elliott, and W. T. Hale. (*Trans. Brit. Ceram. Soc.*, 1954, **53**, Aug., 461–468). The authors have analysed the records of bulk-density and thermal-conductivity routine production control tests on two types of refractory insulating bricks. It is concluded that, for the cases examined, a conductivity estimation from density alone on a single brick is likely to be highly inaccurate, but that an average figure based on the average density of, say, nine bricks would be accurate enough for most practical purposes.—D. L. C. P.

A New Method of Determining the Resistance of Basic Refractories to Thermal Shock. J. Dobrý. (*Hutnické Listy*, 1954, **9**, (7), 397–399). [In Czech]. In the method hitherto used a jet of cold air is directed on the magnesite brick which had been preheated to 950° C. In the new method the brick is replaced by a series of smaller cylinders which are preheated to 1200° C. before forced cooling outside the furnace. The cycle is repeated for each cylinder until about one half by volume is lost due to cracking. The advantages of the new method are discussed.—P. F.

The Creep of Aluminous Refractory Products at High Temperatures. Y. Letort. (*Refract. J.*, 1954, **30**, June 240–243). A brief report is given of an investigation into the influence of the various factors arising in the manufacture of a refractory brick on its mechanical properties at high temperature. Particular attention is paid to the flow curve.

Phase Relationships of Iron-Oxide-Containing Spinels. Part I—Relationships in the System Fe-Al-O. Part II—Relationships in the Systems Fe-Cr-O, Fe-Mg-O, Fe-Al-Cr-O, and Fe-Al-Cr-Mg-O. R. G. Richards and J. White. (*Trans. Brit. Ceram. Soc.*, 1954, **53**, Apr., 233–270; July, 422–459). An investigation is reported on the equilibrium relationship between the sesquioxide and spinel phases of the systems, and a phase diagram has been constructed. Results are also noted which have a significant bearing on the behaviour of chrome and chrome-magnesite refractories in service.

An Electrically Melted and Cast Magnesite-Chrome Refractory. T. Hand and H. W. Baque. (*Amer. Ceram. Soc. Bull.*, 1954, **33**, June, 176–179). Laboratory and commercial procedures developed for evaluating "Corhart 104" are described. Suggested uses for it include high temperature metallurgical applications.—D. L. C. P.

An Approximate Measurement of the Heat Transfer Coefficient of Furnace Refractories. M. Nakamura. (*Tetsu to Hagane*, 1952, **38**, Mar., 115–118). [In Japanese]. A new method for measuring the heat transfer coefficient is based on applying heat to one face for a definite interval, and measuring the impulsive temperature wave at the opposite face.—K. E. J.

Casting Pit Refractories. G. R. Bashforth. (*Refract. J.*, 1954, **30**, May, 182–192). The conditions in which refractories are used for ladles, stoppers, ingot hot-tops and runners are described. The properties required in each case are assessed, the extent to which present materials and methods meet requirements is shown, and possible improvements are pointed out.—D. L. C. P.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Blast-Furnace Design Problems. F. E. Kling. (*Blast Furn. Steel Plant*, 1954, **42**, July, 778–786; Aug., 934–937). A number of improvements in blast-furnace design are discussed. The design of furnace No. 2 at the Ohio works of the Carnegie-Illinois Steel Corp., which was very successful during operation, is described. The production and control of flue dust, with particular reference to application of Stokes' law to the problem, are considered. Improvements in the maintenance of hot blast mains and mixers are suggested.

Accumulation Tests on Cowpers Stoves. Thibaut. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1954, (4), 721–734). Trials have been made on Brohthal and Petit type stoves to assess the advantages of accumulation over normal working. There is a loss of efficiency of 3% and more gas has to be burnt. The process is only economic where excess stove capacity is available and the heat accumulated can be disposed of at a price balancing the above mentioned losses.

Seraphim Project.—1. Recent Plant Modernization and Extensions by the Appleby-Frodingham Steel Company. A. Jackson. (*Iron Coal Trades Rev.*, 1954, **169**, July 23, 188–191). As a background to the recent ironworks extensions at the Appleby-Frodingham Steel Co., the author gives a brief history of the works and describes the major modifications which have been made since the war. The expansion of output is indicated, and the added efficiency of plant already in existence and new capital developments are noted.—G. F.

Seraphim Product—2. The Ideas and Research Behind the Reconstruction. G. D. Elliot. (*Iron Coal Trades Rev.*, 1954, **169**, July 23, 192—194, 202). The author outlines the basic ideas behind the "Operation Seraphim" ironworks extensions at the Appleby-Frodingham Steel Co., and discusses some of the problems which required careful consideration and research. These include the questions of furnace sizes, preparation and quality of the sinter, the furnace burden, and coke quality.—G. F.

Seraphim Project—3. The Design of the Present Ironworks. I. M. Kemp. (*Iron Coal Trades Rev.*, 1954, **169**, July 23, 195–202). The author describes the layout and design of the recently extended ironworks at Appleby-Frodingham Steel Co. He deals first with the two new furnaces and their ancillary equipment, and also gives details of the blowing plant, the crushing and sinter plants, coal pulverization, dust extraction, and the interconnecting conveyor system.—G. F.

Seraphim Project—4. Construction Work for the New Ironworks. K. Paterson. (*Iron Coal Trades Rev.*, 1954, **169**, July 23, 203–210). The author first outlines the supervisory organization of the "Operation Seraphim" construction work at the Appleby-Frodingham Steel Co., and draws attention to matters of general interest in the civil, structural, mechanical, and electrical engineering fields which influenced the site work. Finally, an account is given of the construction sequence and the time-table of the operation.—G. F.

Seraphim Project.—5. Electrical Work for the Appleby-Frodingham Ironworks Extensions. J. L. Gaskell. (*Iron Coal Trades Rev.*, 1954, **169**, July 23, 211–218, 225). The author gives details of the electrical power supply and distribution scheme entailed by the recent ironworks extensions at the Appleby-Frodingham Steel Co. The chief items of plant dealt with are the new blast-furnaces, gas-cleaning plant, blowing equipment and services, and ore-preparation and sinter plants.—G. F.

Seraphim Project—6. Gas: Water: Instrumentation. N. H. Turner. (*Iron Coal Trades Rev.*, 1954, **169**, July 23, 219–224). Details are given of extensions to the gas and water services entailed by the recent ironworks extensions at the Appleby-Frodingham Steel Co., new plant and modifications to existing plant being described. An account is also given of instrumentation and automatic control applied to the blast-furnaces, gas-cleaning plant, sintering plant, boilers, and turbo-blowers.—G. F.

A New Blast-Furnace Charging Mechanism. D. Petit. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1954, (5), 917–925). Trials are described on a bell of new design intended to improve the control of burden distribution on the stockline. The bell surface is made in six equally spaced channels, opposing channels being equal in depth, the depths of the three pairs being 700 mm. It is used with a hopper having a star shaped ridge system deflecting the bulk of the material into six angular positions.—A. G.

Reducibility of Iron-Ore Lumps. A. E. El-Mehairy. (*J. Iron Steel Inst.*, 1955, **179**, Mar., pp. 219–226). [This issue].

Observations on the Working of Blast-Furnaces on Sinter and Lorraine Ore. J. Szczeniowski and P. Thierry. (*Rev. Mét.*, 1954, **51**, May, 305–325: *Iron Coal Trades Rev.*, 1954, **169**, Oct. 8, 857–860). A study has been made of blast-furnaces operating on a sinter and Lorraine ore. Permeability was reduced and the necessity for a high combustion zone introduced cooling difficulties. There was a sharp fall in the coke rate due to the enriched burden and iron quality improved. Details of the trials are given in graphs and tables. A hypothesis is put forward to account for scaffolding and the need for a cooler blast than with ungraded ore.—A. G.

Trials with an Oxygen-Enriched Blast at Moyeuvre. Trentini. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1954, (4), 753–755). Details of trials involving the use of oxygen together with varying additions of scrap, ore, limestone,

and mill-scale are given. Of the casts made, 90% had less than 0·007% nitrogen.—A. G.

Trials at Dilling on the Blowing of Oxygen-Enriched Air. Buey. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1954, (4), 756–760). Liquid oxygen from Nancy transferred to two large cylinders was employed in blast-furnace trials with the addition of ore and limestone at different times. The resultant iron had a phosphorus content of 0·03–0·04% with 15–16% iron in the slag. Ladle desulphurization with soda was necessary. The majority of the casts had less than 0·007% nitrogen.—A. G.

Operating Experience with a Two-Foot Diameter Blast Furnace. R. C. Buehl. (*J. Met.*, 1954, **6**, July, 814–816). Further details of operating experience on the U.S. Bureau of Mines experimental 2-ft. dia. blast-furnace are given from trials on the smelting of Merabi ore, taconite pellets, blast-furnace sinter, and Cuban laterite ore. The results on the different materials are compared, and indicate that considerable information on blast-furnace smelting can be obtained from these small-scale tests.—G. F.

Pig Beds: A Method of Machine Moulding. G. S. Milburn. (*Iron Steel*, 1954, **27**, Aug., 409–410). At Dorman Long & Co. Ltd., surplus iron from the blast-furnaces is cast in pig beds which are raked and re-moulded by devices fitted to a small tractor, an 80-ton capacity section being dealt with in 1½ hr. Details of the operation and tractor equipment are given.—G. F.

Metallurgy of the Blast-Furnace. T. Kootz, A. Michel, and H. Rellermeyer. (*Arch. Eisenhüttenwesen*, 1954, **25**, July-Aug., 299–306). In smoothly working furnaces using a low-manganese burden, reduction of silicon precedes that of manganese. In the hearth, equilibrium of these two components between metal and slag is not attained. Whilst the silicon content may indicate the reduction conditions before the separation of iron and slag, the deviation of manganese and silicon concentrations from equilibrium values is characteristic of conditions in the hearth. With irons from the above-mentioned burdens, carbon saturation in the hearth is by no means attained. The carbon content depends on those factors which control the degree of reduction in the stack and in the hearth. Carburization of the iron precedes the reduction of the other elements by solid carbon; equilibrium between solid carbon and the components of metal and slag is not reached. Approximately 25% of the silica in normal blast-furnace slags can be reduced into the iron.—J. P.

Equilibrium Relations Between Pig Iron of Fe-C-Si System and Slags of SiO_2-CaO-Al_2O_3 System Under One Atmospheric Pressure of CO. H. Sawamura and J. Sawamura. (*Tetsu to Hagane*, 1952, **38**, June, 361–365). [In Japanese]. At constant temperature, increase in slag basicity increased the carbon content and decreased the silicon content of the iron. At constant basicity, increase of temperature increased the silicon in the iron, but the carbon hardly changed.

K. E. J.

Iron as a Catalyst in the Decomposition of Carbon Monoxide. P. P. Das and B. Chatterjee. (*Trans. Indian Inst. Met.*, 1952, **6**, 279–284). The reaction $2CO = CO_2 + C$ is catalysed by metallic iron and the activity of the catalyst decreases with continued heating in the gas. Treatment of the deactivated catalyst with hydrogen restores its activity. If heated in hydrogen or nitrogen before interaction with carbon monoxide the catalyst decreases in activity, the greatest reduction occurring at the highest temperature of treatment.

Thermodynamics Applied to Ferrous Metallurgy. J. Givaudon. (*IRSID, Centre d'Etudes supérieures de la Sidérurgie*, Metz, 1953, "*Les Cahiers du CESSID*" *No.* 1). The fundamental thermodynamic functions such as free energy, enthalpy, entropy and specific heat are defined and discussed, with the inclusion of values for substances of interest in iron making. Chemical potential, the phase rule, and the law of mass action are also treated. The reactions involved in the gasification of carbon and in the reduction of iron oxides in the blast-furnace are dealt with in detail both from thermodynamic and kinetic aspects. Other reactions such as desulphurization and the formation of silicates are also considered.—A. G.

The Duffield Process for the Manufacture of Iron. G. Zuliani. (*J. Four Elect.*, 1954, **63**, Mar.-Apr., 45–46). A short account is given of this process which uses pulverized iron ore and a slag in an electric furnace. Iron containing 0·02% C, 0·01% Si, and negligible phosphorus can be obtained. Details of the amount of materials used are given.

B. G. B.

The Electro-Metallurgical Works at Chimbotte in Peru. (*J. Four Elect.*, 1954, **63**, Mar.–Apr., 46–47). A brief description is given of electric furnaces for the smelting of iron ores and electric steelmaking in Peru.—B. G. B.

PRODUCTION OF STEEL

The Reorganization of the Italian Iron and Steel Industry. G. Coppa-Zuccari. (*Mét. Constr. Mécan.*, 1954, **86**, July-Aug., 557–560). A short account is given of new plant and equipment which has been installed in the Italian iron and steel industry since 1945.—B. G. B.

Soviet Progress: Some Interesting Developments in Iron and Steel Production Behind the Iron Curtain. R. Sewell. (*Iron Steel*, 1954, **27**, Aug., 421–422, 424). From recent published reports, the author draws attention to some significant developments in iron and steel production in Russia and East Germany. The subjects mentioned include the production of producer gas with increased calorific value, low-shaft furnace production, studies of runner brick quality, and methods of tapping heats into twin ladles.—G. F.

Lackenby: Open-Hearth Steel Works. (*Engineer*, 1954, **198**, Aug. 6, 190–193; Aug. 13). **Lackenby: The Dorman Long Development Plan.** (*Iron Steel*, 1954, **27**, Aug., 387–398). Following a brief outline of post-war developments at Dorman Long & Co. Ltd., a detailed account is given of the new Lackenby Works. The layout of the works is described and illustrated, and full details are given of the melting shop, the furnaces and mixers, and their auxiliary equipment. Other items considered include raw materials handling, ingot handling, rolling stock, and gas, water, steam, and electricity services.—G. F.

Iron and Steel Production in India: Reconstruction and Expansion Plans. (*Iron Coal Trades Rev.*, 1954, **169**, Aug. 27, 531–532, 530). An outline is given of the major iron and steel producing units in India, with details of the current reconstruction and development plans, including the plans for the new works to be erected at Rourkela.—G. F.

Wheeling Steel Corporation's Steubenville Works. C. Longenecker and H. E. Trout. (*Blast Furn. Steel Plant*, 1954, **42**, Aug., 902–927). A comprehensive account of this integrated iron and steel plant is given. The principal product is steel in the form of coils or sheets, and products made from them, *e.g.*, tinplate, pipe, and galvanized ware. The annual ingot capacity is 2,130,000 short tons and coke capacity is 1,720,000 short tons which is sufficient for the Corporation's six blast furnaces.—B. G. B.

Oxygen Converter Steel—Another Step Closer to U.S. Debut. W. C. Rueckel and W. A. Vogt. (*Steel*, 1954, **135**, July 19, 110–114). The process is considered in relation to its profitable employment in the U.S.A. following its success in Austria. Some 30 tons of pig iron and 10 tons of scrap in a vessel are blown with 95%-pure oxygen through a vertical water-cooled lance. Open-hearth quality steel may be produced at the same cost and in the same quantity as Bessemer steel. Figures typical of the process are given.—D. L. C. P.

Basic Bessemer Steelworks—Heat Balance of a Basic Converter. J. Givaudon. (*IRSID, Centre d'Etudes supérieures de la Sidérurgie*, Metz, 1953, "*Les Cahiers du CESSID*" *No. V*). Difficulties arising from inadequate data on temperature and gas composition are stressed. A heat balance is worked out for a typical charge, the CO_2/CO ratio in the exit gases being determined indirectly from carbon and oxygen balances.—A. G.

The Problem of Reducing Nitrogen Absorption in the Basic Bessemer Converter. R. Baake, H. Eisenreich, and K. Schröder. (*Met. u. Giesserei Techn.*, 1954, **4**, June, 253–254). Experiments to determine how far the nitrogen content of steel in a basic-Bessemer plant could be reduced without the aid of oxygen are described. It is claimed that the nitrogen content was considerably reduced by: (1) Increasing the air pressure; (2) charging the converter with liquid iron at high temperature; (3) low pouring temperature; and (4) adding calcium carbonate throughout the blow.—R. A. R.

On the Basic-Bessemer Process P. Coheur and H. Kosmider. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**: *J. Met.*, 1954, **6**, July, 829–835). The authors discuss the industrial possibilities of the basic-Bessemer process in the manufacture of rimming steel, basing their remarks on European experience of blowing with air, oxygen-enriched

air, and mixtures of oxygen and steam. The quality of steels produced by these processes is discussed, and it is shown that sulphur and phosphorus contents of 0·02% and nitrogen contents of 0·002% can be obtained by the new blowing methods. The methods offer outstanding economic possibilities.—G. F.

Basic Bessemer Steelworks—The Converter. M. Tavard. (*IRSID, Centre d'Etudes supérieures de la Sidérurgie*, Metz, 1953, "*Les Cahiers du CESSID*" *No. V*). A detailed account is given of the principles governing the design and construction of the converter and its lining together with a description of the wind box, air supply, and tilting mechanism. The fabrication of converter bottoms is discussed and factors influencing their life are considered. Finally, the converter is treated as a unit of production taking into account the factors limiting its output.—A. G.

European Oxygen Steelmaking Is of Far-Reaching Significance. H. B. Emerick. (Amer. Inst. Min. Met. Eng., Open-Hearth Conf., 1954: *J. Met.*, 1954, **6**, July, 804–806). The author gives details of recent developments in Europe in the application of oxygen in metallurgical processes. These include enrichment of the compressed air blast for low-shaft blast-furnace operation, enrichment of air used in bottom-blown basic-Bessemer practice, pre-refining of basic iron in hot-metal ladles, nitrogen-free mixtures of high-purity oxygen and steam in basic-Bessemer practice, and top-blowing in solid-bottom basic-lined converters.—G. F.

The Rôle of Aircraft Research in Furnace Design. J. H. Chesters. (*Iron Steel*, 1954, **27**, June, 207–212; June 12, 246–251). The author discusses points of similarity between aerodynamic and furnace problems, and suggests that substantial progress in open-hearth furnace design may come from the wealth of fundamental information obtained in aeronautical research. Furnace equivalents of aerodynamic phenomena are considered, including breakaway, recirculation, instability, secondary flow, and obstructions to flow. Laboratory water models of furnaces are then discussed and the application of aerodynamics to open-hearth development is considered, taking as an example the development of the sloping-end single-uptake furnace.—G. F.

The Open-Hearth Furnace—General Description—Construction. S. Terrat. (*IRSID, Centre d'Etudes supérieures de la Sidérurgie*, Metz, 1953, "Les Cahiers du CESSID," No. II). After an outline of the principles of this method of steelmaking a brief description is given of the various parts of the open-hearth furnace. The different types of furnace are mentioned, the fixed being in general preferred to the tilting type. An extremely detailed account of the construction of open-hearth furnaces is given together with a review of the main working difficulties and means of overcoming them. Regarding choice of burner design, that with vertical air delivery, as in the Maerz furnace, is considered superior for refining mild and low-alloy steels and the surprisingly small use of this method is commented on.—A. G.

An Improved Model for the Calculation of Heat Transfer in the O.H. Furnace. M. W. Thring and D. Smith. (*J. Iron Steel Inst.*, 1955, **179**, Mar., 227–230). [This issue].

Special Construction of Chrome Magnesite Burners on a 70-ton Maerz Furnace Fired by Producer Gas. Savarre. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1954 (4), 735–743). Maerz type burners are simple in design but the inclination and direction of gas ports, and the arch height must be accurately controlled. Trials on a modified design of burner using chrome-magnesite refractory are described, and improved operation and working are reported.—A. G.

Iron and Steel Chronicle. G. Grenier. (*Écho Mines*, 1954, June, 381–384). The advantages and disadvantages of the open-hearth and basic-Bessemer processes for the manufacture of steel are discussed, particular reference being paid to European conditions. A short account of the development of the open-hearth process since 1864 is given.

Reducing the Repair Time in Open-Hearth Furnaces. F. Franz. (*Met. u. Giesserei Techn.*, 1954, **4**, May, 214–219). At Brandenburg, five days are now normally required to prepare a 120-ton Maerz furnace. Nine of the ten furnaces are therefore in operation at a time. Each furnace has to last 100 heats without intermediate repairs. In 1952, 82% efficiency was attained. The method of operation is briefly described.—L. J. L.

Self-Propelled Dolomite Machine. (*Brit. Steelmaker*, 1954, **20**, Sept., 370–371 : *British Eng.*, 1954, **37**, Sept., 87–89). **Mobile Dolomite Fettling Machine for Open-Hearth Furnaces.** (*Mech. Handling*, 1954, **41**, Sept., 547–550). A description is given of a new dolomite fettling machine, developed by Blaw Knox, Ltd., for melting shops not equipped with rail tracks. It runs on rubber-tyred wheels and is powered by a diesel engine. It has a variable rate of projection up to 1 ton/min., and the dolomite powder can be accurately placed with a throw of 43 ft. maximum.—K. E. J.

The Supply of Scrap to Open-Hearth Furnaces. M. D. J. Brisby and W. O. Pendray. (*J. Iron Steel Inst.*, 1955, **179**, Mar., 252–260). [This issue].

Charging Delays Due to Furnace Bunching. A Method of Assessment. R. Solt. (*J. Iron Steel Inst.*, 1955, **179**, Mar., 260–264). [This issue].

Survey Provides Analysis of Cold Metal Shop Melting Practice. S. L. Fredericks. (Amer. Inst. Min. Met. Eng. Open-Hearth Conf., 1954: *J. Met.*, 1954, **6**, Aug., 880–882). The author discusses and analyses data on charging and fluxing practices in cold-metal basic open-hearth melting shops, returned by a number of works in response to a questionnaire.—G. F.

Iron Oxide Deposition in Open-Hearth Furnaces. M. J. McInerney. (*J. Iron Steel Inst.*, 1955, **179**, Mar., 248). [This issue].

Slag Control in the Basic Open-Hearth Furnace. M. Bernard. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1954, **4**, 771–784). A consideration of the mechanisms of the elimination of carbon, sulphur, and phosphorus, and of the recovery of manganese shows that all these processes are governed by slag basicity and oxygen content. Means of assessing these slag properties under given conditions of operation are discussed with the aid of examples.—A. G.

Thermodynamic Treatment of Fused Salts and Slags. T. Förland. (*Jernkontorets Ann.*, 1954, **138**, (8), 455–478). [In Norwegian]. In a review of ion exchange equilibria, the equilibrium constant for anion exchange in a mixture is shown to be given by

$$\ln K_{\text{mixture}} = N'M_1 \ln K_{M_1} + N'_{M_2} \ln K_{M_2} + \ldots.$$

in which K_{M_1} is the equilibrium constant in a system containing only the cation M_1, and N'_{M_1} is a concentration term. The use of this equation is demonstrated on the metallurgical equilibria for the distribution of phosphorus and manganese between a fused slag and liquid iron. In addition, the activity of one salt component in a mixture of fused salts is calculated. The formation of two liquid phases and the deviation of the ions in the mixture from random distribution are also discussed.—G. G. K.

Thermodynamics and Slag Structure. J. Mamecki. (*Foundryman* (Stalingrad), 1950, (7, 8), 190–195: *Met. u. Giesserei Techn.*, 1954, **4**, July, 314–318). The general characteristics of slag are discussed, the following aspects being dealt with: The free energy of silicates; activity of the components in binary systems and in silicates; the hypotheses of Schenck and Chipman; investigations of silicate structure in the solid state; research by Russian scientists; and the ion hypothesis.—L. J. L.

On the Viscosity of Molten Slags. T. Saito and Y. Kawai. (*Tetsu to Hagane*, 1952, **38**, Feb., 81–86; Sept., 630–634). [In Japanese]. Studies were made on synthetic slags at 1500–1600° C., using a viscometer. With CaO–SiO_2 slags at 1600° C., the addition of SiO_2 increased the viscosity, but Al_2O_3 had little effect until it exceeded 20%. The viscosity of CaO–Al_2O_3 was low, comparable with the low-viscosity region of CaO–SiO_2 slags. MgO decreased the viscosity of CaO-SiO_2 slags, up to 20% additions. The addition of MgO to CaO–SiO_2–Al_2O_3 slags decreased the viscosity, but the beneficial effect was less than has previously been reported, being approximately equivalent to that of CaO. (15 references).—K. E. J.

Rapid Method of Measuring Slag Basicity. K. Shinji. (*Tetsu to Hagane*, 1952, **38**, Mar., 146–150). [In Japanese]. A rapid method of measuring slag basicity was investigated, using a reflex microscope, which gave a result in 5–15 min., but this was not applicable to electric furnace practice. A method based on the lustre and creases in the pancake surface, porosity of fracture, and colour of the powder was therefore devised, which gave the CaO/SiO_2 ratio and total FeO only 3 min. after taking the pancake, with little loss in accuracy compared with microscopy.—K. E. J.

Attempts to Lower Slag Basicity in the Open-Hearth Furnace. J. Zieba. (*Wiadomosci Hutnicze*, 1953, (1), 8–11: *Met. u. Giesserei Techn.*, 1954, **4**, July, 311–313). The

author describes experiments carried out in Poland with furnaces of 20–50 ton capacity working with 25–50% pig iron charges. A good steel was obtained when the basicity on tapping it off, was 2·5 or 3·0. This basicity sufficed to keep phosphorus and sulphur contents within the prescribed limits; they remained within these limits even with a slag basicity of 1·6.—L. J. L.

The Electrical Conductivity of Molten Binary Slags. K. Mori and Y. Matsushita. (*Tetsu to Hagane*, 1952, **38**, May, 283–288). [In Japanese]. Studies were made on the systems Na_2O–SiO_2, CaO–SiO_2 and MnO–SiO_2. The conductivities increase with temperature, and with increase of basic oxide content.—K. E. J.

The Electrical Conductivity of Molten FeO–SiO_2 and FeO–MnO–SiO_2 Slags. K. Mori and Y. Matsushita. (*Tetsu to Hagane*, 1952, **38**, June, 365–371). [In Japanese]. Conductivities were measured in the range 100–1420° C. Conduction was ionic in the molten state, but electrons also took part in the solid state; it decreased with increase in silica.

Activities of Fe, FeO, Fe_2O_3, and CaO in Simple Slags. H. R. Larson and J. Chipman. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**: *J. Met.*, 1954, **6**, June, 759–762). Using previously obtained data, the authors have computed the activities of iron, FeO, Fe_2O_3, and CaO in slags of the simple ternary system CaO–FeO–Fe_2O_3, and of iron, FeO, and Fe_2O_3 in quasi-ternary systems involving fixed lime/silica ratios of 2·235 and 1·306. The results are represented graphically.—G. F.

The Iron-Sulphur-Oxygen System and Its Importance as a Basis for the Decomposition of Iron Sulphides with Sulphur Dioxide to Form Iron Oxide and Sulphur Vapour. N. G. Schmahl. (*Arch. Eisenhüttenwesen*, 1954, **25**, July-Aug., 315–319). Thermodynamic considerations have been used to decide on the reactions which are possible in the Fe–S–O system, the conditions under which they can occur, and their equilibrium states. These are given in tabular and graphical form for temperatures of 600°, 700°, 800° and 900° C. A new method is proposed for the graphical treatment of such ternary systems.—J. P.

Electric Energy Consumption of Héroult Type Electric Arc Furnaces. M. Nakamura. (*Tetsu to Hagane*, 1952, **38**, Apr., 207–213). [In Japanese]. Furnace data are analysed statistically, and an equation giving the energy consumption in terms of the charge quantity and melting period is derived.

Single-Phase or Three-Phase Furnaces? M. Kaufmann. (*J. Four Elect.*, 1954, **63**, Mar-Apr., 41–42). The use of these two methods for electric furnace operation is discussed and the advantages of three-phase operation of furnaces are explained.—B. G. B.

Mechanizing and Accelerating the Relining of Basic Electric Arc Furnaces. O. Schick. (*Met. u. Giesserei Techn.*, 1954, **4**, May, 198–205). By using prefabricated sections of rammed dolomite the relining time for 5–10 ton electric arc furnaces was reduced from 300 to 200 man-hours. The method of setting up the moulding boxes and making the prefabricated sections is described and illustrated.—R. A. R.

The Rapid Repair of Electric Furnaces. F. Mack. (*Met. u. Giesserei Techn.*, 1954, **4**, May, 205–213). The author reports the success of the Russian method of using prefabricated dolomite sections for lining the 20-ton electric furnaces at Maxhütte. The old lining is removed by means of a hook attached to a crane ripping the lining off from bottom to top. A hollow-bottom water-cooled platform is fitted in the furnace before ripping. This enables the whole re-lining process, which used to take 17 hr., to be completed in 7 hr.—L. J. L.

Special Clays for Lining Electric Steel Furnaces, and in Particular High Frequency Furnaces. Seloron. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1954, (4), 745–752). Linings for arc and acid high-frequency furnaces are generally satisfactory but this is not so for the basic high-frequency furnace melting steels high in manganese or chromium. Operational trials of special linings are reported giving excellent results but their high cost limits their use at present.

Reducing the Preparation Time of Basic Electric Arc Furnaces. H. Müller. (*Met, u. Giesserei Techn.*, 1954, **4**, May, 195–198). Details are given of the raw materials and methods of making tar dolomite segments which are used for the rapid relining of arc furnaces of up to 15 tons.—R. A. R.

The Influence of Trace Elements and Gases on the Quality of Steel Products. M. Šícha. (*Hutnické Listy*, 1954, **9**, (7), 386–397). [In Czech]. Works experiments were carried out with plain and low-alloy low-carbon steel of the open-hearth and duplex types to determine the conditions of oxygen pick-up during pouring, and the effect of gases, trace elements, and inclusions on the quality of the final product. Oxygen in liquid steel was determined by a modified Herty method. Turbulence of the stream during pouring led to a high oxygen content. The contents of oxygen and non-metallic inclusions depended appreciably upon the manner of handling the slag just before pouring began. Moist refractories also induced similar effects. Steel with more than 0·025% As was inferior to arsenic-free steel, but specimens containing 0·04% Sb and 0·11% Sn were not significantly lower in quality.

New Exothermic Technique for Pouring Ingots. P. Venard. (*Steel*, 1954, **134**, June 28, 111–114, 122). The investigation of a method for reducing the ingot-top loss and the technique developed are described. Cast-iron tops lined with exothermic flat refractory plaques (of 'Exothermal') considerably reduce the pipe and segregation in an ingot.—D. L. C. P.

Recent Achievements in the Field of Continuous Casting of Steel. J. Gouzou. (*Pub. l'Assoc. des Ing. Faculté Polytechn. Mons*, 1953, (4), 5–11, 1954, (1), 10–22). A comprehensive survey is presented of the development of continuous casting methods. Outlines are given with diagrams of the semi-industrial scale plants of Babcock-Wilcox Tube Co., and Allegheny-Ludlum Steel Corp. in the U.S., and of Huckingen A.G. in Germany. Plants to be built in Canada and in England are mentioned. A number of experimental plants are also mentioned, including those at Kapfenberg in Austria, and at B.I.S.R.A.'s laboratories in England. Recent patents on the subject are reviewed, with particular reference to the perfection of vertical casting and the rapid cooling of the billet. Methods using graphite moulds, asymmetric chilling, enclosed billets, and intermittent withdrawal are mentioned. Direct casting of sheet and casting of ingots on endless chains are described. The methods are discussed. (94 references).—J. E. D.

Scrap Disposal and Scrap Stocking Ground Organization in Steelworks. V. Štorek and J. Pech. (*Hutnik*, (Prague), 1954, **4**, (7), 195–197). [In Czech]. Efficient methods of storing and sorting scrap are discussed, and the effect on steel of various non-metallic and metallic impurities frequently adhering to scrap are considered.—P. F.

On Huge Carbides in the Ball-Bearing Steel Billets. K. Deguchi. (*Tetsu to Hagane*, 1952, **38**, June, 406–413). [In Japanese]. Large carbide particles, resembling MnS slags, were observed at the cores of the billets, in the segregation zone. Their properties, and the effects of various elements on their appearance, are described. They appear to be eutectics separating where the grain boundary segregations of carbon and phosphorus exceed a certain limit.—K. E. J.

Effect of Chromium on Non-Metallic Inclusions in Molten Steel. H. Ishizuka. (*Tetsu to Hagane*, 1952, **38**, Mar., 143–146; Apr., 182–187; Aug., 525–531). [In Japanese]. The effects on non-metallic inclusions high in chromium at melt-down, and before final refining, ferrochromium additions in the last period of refining, and high chromium content before tapping, are summarized. In the basic arc furnace there is little effect; in the basic open-hearth furnace no distinct influence; and in the acid open-hearth furnace a marked increase, for each case. The inclusions in a low-chromium steel were studied microscopically, and found to be of the SiO_2–Cr_2O_3 and SiO_2–MnO–Cr_2O_3 systems. SiO_2 and Cr_2O_3 readily formed a solid solution, while MnO and Cr_2O_3 did not; SiO_2, MnO and Cr_2O_3 formed a eutectic of the ternary system.—K. E. J.

Ingot Cracks in Killed, Fine-Grained C1020 Steel. M. A. Orehoski, N. R. Arant, and J. A. Pusateri. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200** ; *J. Met.*, 1954, **6**, Aug., 891–899). The authors summarize the results of works and laboratory investigations of the formation of ingot cracks in killed, fine-grained 0·20% C steel. Sectioned ingots show wave-like patterns of white bands near the surface, cracks occurring at the positions where the bands are nearest the surface. Poured-out laboratory ingots show that the white bands indicate an uneven solidification front caused primarily by turbulence during teeming. Methods developed in the laboratory for reducing turbulence, namely teeming into liquid slag and multiple-nozzle teeming, proved on the works scale to be effective in reducing the incidence of cracks.

FOUNDRY PRACTICE

The Remelting in the Cupola of Ferrous Materials and the Problem of Carbon in Foundry Iron. J. Pascal. (*Mét. Constr. Mécan.*, 1954, **86,** May, 385–393; June, 497–511). A detailed examination is made of the problems of producing foundry iron by the cupola process using materials not always high in iron. The influence of silicon and phosphorus on the maximum possible amount of carbon in the iron and on the rate of carburization is considered and equations and graphs relating maximum carbon content and rate of carburization to the silicon and phosphorus content are given. Results obtained by other workers on the recirculation of iron through the cupola for a number of times, particularly with regard to changes in carbon, silicon, sulphur, and phosphorus contents are described. The composition of the cupola charge and the analysis of the iron produced are given for 23 special types of iron.—B. G. B.

Oil-fired Cupola Furnaces. E. E. Geiger. (*Tecn. Industr.*, 1954, **32,** Mar. 185–186). [In Spanish]. A cupola fired with oil or coke is described with details of the special oil burner.

Die-Pressing of Gutters. R. S. M. Jeffrey and J. A. Richards. (*Inst. Brit. Found.*, 1954, June 22–25, *Paper No.* 1097). A detailed description is given of the die-pressing process used by Federated Foundries Ltd., for the production of cast-iron gutters. In this process, metal is poured into a female die and the gutter formed by the closing of a male die. The operating cycle is automatically controlled so that the male die cannot enter the metal at an uncontrolled speed and is arranged so that opening of the dies and the signal for removing the casting may be preset. The die opens as soon as solidification is complete so as to prevent the formation of a chill-cast white iron.—B. C. W.

Centrifugal Casting. A. J. Gibbs Smith. (*Gas World*, 1954, **140,** Aug. 21, Suppl. 30–31). A centrifugal casting machine of the horizontal-axis type, embodying latest German practice, is described. The Ardeltwerke G.m.b.H., Wilhelmshaven, plant for the production of cast-iron pipe consists of a casting machine, pouring trolley, draw-bench for withdrawing the pipe from the mould a mould magazine holding four moulds which are pre-heated by gas before use and air-cooled after use. Pre-heating temperature is 250°–300° C. and pouring temperature is 1200°–1260° C. Production is 30–40 pipes/hr. Operating costs and advantages of the method over normal sand casting are discussed.—T. E. D.

Shell Moulding Equipment. (*Engineer*, 1954, **198,** July 2, 13–14: *Automobile Eng.*, 1954, **44,** July, 281–284: *Machine Shop Mag.*, 1954, **15,** July, 387–390: *Metallurgia*, 1954, **50,** July, 34–36). An integrated range of shell moulding machines and equipment which has been developed by the Polygram Casting Co. Ltd., now includes machines taking pattern plates up to 22 × 24 in., automatic shell core making machines, and mould closing machines.—M. D. J. B.

"D" Process for Precision Castings. H. W. Dietert. (*Inst. Brit. Found.*, 1954, June 22–25, *Paper No.* 1094). The advantages of, and methods available for, precision casting are briefly reviewed and the "D" process is then discussed at length. The process uses a metal pattern which is mounted together with gates on a blow plate, and a heated core-carrier contoured around the pattern so as to leave a $\frac{3}{8}$ in. space for the core sand. The half mould is blown on a normal core-blowing machine and then baked in a core oven. Details are given of sand, binders, patterns, gating, venting, core carriers and methods for clamping the half moulds.

Investment Casting Works. (*Engineer*, 1954, **198,** July 9, 63–64: *Engineering*, 1954, **178,** July 16, 79–80: *Machine Shop Mag.*, 1954, July, 383–386). These articles describe the new works recently opened at Droitwich by Deritend Precision Castings, Ltd., for the production of small precision castings by the lost wax or investment casting process. The casting capacity of the shop is 600 lb. of metal per shift and the techniques enable castings to be produced with overall tolerances of 0·005 in.—M. D. J. B.

Eutectic Solidification in Grey, White, and Mottled Cast Iron of Hypoeutectic Composition. A. Hultgren, Y. Lindblom, and E. Rudberg. (*Gjuteriet*, 1954, **44,** July, 109–124). [In Swedish]. Solidification under controlled conditions was studied in four cast irons, samples being quenched at predetermined points on the cooling curves and examined for evidence of processes occurring during cooling. The appearance of the graphite and austenite components and their general manner of development in relation to the cooling curves indicated direct formation from the melt by eutectic reaction.—G. G. K.

Centrifugal Method of Metallurgical Research. R. V. Riley and B. T. Gillyat. (*Inst. Brit. Found.*, 1954, June 22–25, *Paper No.* 1101). A detailed description is given of an apparatus which enables small specimens of cast iron to be melted and solidified whilst under a centrifugal force of about 1000g. Experiments with phosphoric grey iron showed that the high pressure stabilizes the carbide and causes inverse chill and super-cooled graphite. Complete separation of the sulphide from the melt was not achieved by centrifuging and the reasons for this are discussed. The agglomeration of phosphides in centrifuged specimens was observed and is attributed to combination of high pressure and thermal currents. The distribution of silicon and trace elements was not affected by centrifuging.—B. C. W.

Correlation of the Properties of Castings and Test-Bars in Grey Cast Iron. E. O. Lissell and M. Itzel. (*Inst. Brit. Found.*, 1954, June 22–25, *Paper No.* 1103). The different ways of correlating test-bar and casting properties in grey cast iron are compared and discussed. It is pointed out that although the relationship between one ruling test-bar and other round bars can be established statistically, no two-way relationship can be evaluated between two or more test-bars.

Effects of Calcium Silicide on Cast Iron (I). T. Kusakawa. (*Tetsu to Hagane*, 1952, **38,** June, 376–382). [In Japanese]. In iron containing > 25% of nickel, 3% of Ca_3Si produced the spheroidal graphite structure: irons with 10–25% of nickel needed 5%. For hypereutectic iron not containing nickel, 5–10% of Ca_2Si produced the spheroidal structure. The shrinkage cavities of these irons were smaller than when magnesium is used, and the running properties were good.—K. E. J.

The Work of the Laboratories Technical Committee of the Centre Technique des Industries de la Fonderie (C.T.I.F.). M. Ballay. (*International Foundry Congress*, Paris, Sept. 19–27, 1953, *Paper No.* CI-46). [In French]. The activities and achievements of the central and branch laboratories of the Centre Technique des Industries de la Fonderie are reviewed. Among the fields of work being tackled are methods and reproducibility of chemical analysis, sand testing, and corrosion testing.—B. C. W.

The Suppression of Dust-Prevention and Control in Foundries. W. B. Lawrie. (*Engineering*, 1954, **178,** July 9, 36–37). An account is given of the Summer Meeting of the Institution of Heating and Ventilating Engineers. The questions of dust elimination and control are discussed as well as its effects on health. Methods of counting and sampling particles are described.—M. D. J. B.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Case Hardening Steel By Carbonitriding. (*Steel*, 1954, **135,** July 26, 98–102). A general account of carbonitriding is given with special mention of recent trends in practice. The effect and benefits of the treatment on various steels, the plant involved, and examples of its application are described.—D. L. C. P.

Oxy-Acetylene Stress Relieving of Pressure Vessels. H. Kunz. (*Welding J.*, 1954, **33,** June, 288s–294s). A study was made of stress relief in welded vessels using temperatures below 200° C. The results show that a worthwhile reduction in stresses can be secured by simple apparatus. The reduction in longitudinal stresses in the shell girth seam was 69–80%; for transverse stresses the reduction was about 60%. These results are practically the same as for plane plates.

Stress-Relieving of Large Fractionating Column. (*Engineer*, 1954, **198,** Sept. 3, 327). An account is given of stress-relieving procedure on a high-pressure oil fractionating column 120 ft. long by 3 ft. 8 in. in dia.—M. D. J. B.

Anneal Furnace Makes Double Play. W. M. Hepburn. (*Steel*, 1954, **134,** June 14, 128–129). The sequence of operations used for turning out 90-mm. brass or steel cartridge cases is given. Each of the two direct convection heated roller-hearth furnaces can be used to anneal either steel or brass cases before drawing, at up to 700/hr.—D. L. C. P.

Hardening by Induction. D. Warburton-Brown. (*Mech. World*, 1954, **134,** May, 212–215, 229–231). The application of induction heating to the hardening of steel is described. The effect of supply frequency, coil design, and work-piece

size and shape on the heating effect produced is fully discussed.—D. H.

Below Zero Heat Treatment. R. S. Jamison. (*Steel*, 1954, **134**, June 28, 104–106). Low temperature treatment is being used on a production basis for obtaining more complete transformation of austenite to martensite and for shrink fitting. Examples of applications are given. By incorporating a —120° F. chill in the heat-treatment the stability of precision parts and the transformation in high-chromium steels are improved.—D. L. C. P.

Fundamentals of Quenching—Design for Batch Treatment Systems. A. J. Jarema. (*Steel*, 1954, **134**, June 7, 110–112; June 14, 114–116). Factors affecting the type and size of the various components in a batch quenching system are pointed out, and examples of design calculations are given.

Fundamentals of Quenching—Interrupted Quench Gives Special Properties. N. K. Koebel. (*Steel*, 1954, **134**, June 21, 128–130). The mechanism, and practice of austempering, martempering, and cyclic annealing by interrupted quenching are described.—D. L. C. P.

Studies of Quenching Method of Hollow Steel Rod Prepared for Test. T. Tanaka and Y. Imai. (*J. Mech. Laboratory*, 1950, **4**, July, 75–79). [In Japanese]. Methods of quenching hollow drill steel for percussion drilling were studied. The best method of preventing cracks was to immerse all the drill except the tip and then quench the tip 1 sec. later.

End-Quench Hardenability and Evaluation of Quenching Media. S. C. Das Gupta and D. S. Eppelsheimer. (*Trans. Indian Inst. Met.*, 1952, **6**, 96–103). An evaluation of water, sodium silicate solutions, Gulf Super-quench, Houghton No. 2 Soluble and 'Houghto-quench' oils was attempted using the A.S.T.M. end-quench hardenability test. The effect of using different quenching media on steels of similar hardenability but different chemical composition was studied.—D. H.

On the Quenching Media for Steels. M. Tagaya, I. Tamura, and S. Nabeshima. (*Tetsu to Hagane*, 1952, **38**, Jan., 5–8). [In Japanese]. The quenching of eutectoid steel from 780° C. was investigated by a thermoelectric method. The only aqueous coolant similar to oil was water-glass. Aqueous solutions had drastic effects, and the cooling power of colloidal solutions could readily be modified. The cooling ability of oils increased with molecular weight, fatty oils being better than mineral oils unless the acid value was high.—K. E. J.

FORGING, STAMPING, DRAWING AND PRESSING

Precision in Die Forging. O. Kienzle. (*Rev. Gén. Méc.*, 1954, **38**, June, 185–188). Factors limiting the precision of the die forging process are examined. These include die wear, the thickness of material, and eccentric working.

Forging and Hot Forming. G. P. Holman. (*Indust. Heating*, 1954, **21**, Mar., 474–480, 616–618; June, 1090–1094, 1246–1250). In Part I forging methods and machines are reviewed. The relative merits of forging presses and steam hammers are discussed and die lubricants described. Part II deals particularly with the heating. Maximum forging temperatures for steels of different carbon contents are given. Overheating is a phenomenon associated with heating 100° F. above the maximum forging temperature resulting in grain coarsening without oxidation, whereas with burning, oxidation in the grain boundaries occurs. Water jets at 1800 lb./sq. in. provide the best method of descaling. Slot, continuous, and induction furnaces are described. Thermal efficiencies of 8·5–15% and 25% are given for slot and pusher furnaces respectively.—B. W. B.

Stock Preparation for Forging Press or Drop Stamp. (*Engineering*, 1954, **178**, Aug. 27, 277–278). This article describes a range of roll forging machines to deal with bars from 1½ to 5 in. thick, made by Wilkins and Mitchell, Ltd., Darlaston, which incorporates effective means of achieving all required adjustments positively and rapidly.—M. D. J. B.

Forgeability of Steels with Varying Amounts of Manganese and Sulphur. C. T. Anderson, V. V. Donaldson, R. W. Kimball, and F. R. Cattoir. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**, *J. Met.*, 1954, **6**, July, 835–837). The authors have determined the limit of forgeability of steels containing varying amounts of sulphur and manganese, using high-purity materials and a standardized melting, teeming, and forging practice. Manganese-free steels containing more than 0·017% S could not be forged, whilst above 0·03% S and 0·06% Mn, the relationship percentage Mn required = 1·25 × %S + 0·03 holds. Variation in carbon and added aluminium had no significant effect.—G. F.

The Case for Cold Heading. D. H. Samuelson. (*Steel*, 1954, **135**, July 12, 110–111). Examples of what can be achieved by cold heading, and considerations in the design of such parts are described.—D. L. C. P.

Radial Forming Technique for Fabricating Sheet Metal Parts. (*Welding and Metal Fab.*, 1954, **22**, Aug., 286–287). The American Ryan Aeronautical Company has developed a new 'expansion-forming' technique for fabricating aluminium and stainless steel components. The principal feature is the mandrel press with a radial force of 4800 tons.—U. E.

Pumps and Distributors for Hydraulic Presses. F. H. Towler. (*Soc. Roy. Belge. Ing.*, 1954, Mar., 139–150). The use of hydraulic methods for the control of hydraulic presses in place of the more usual mechanical, electrical, or servo-motor methods is discussed. The application of this principle to stamping, forging, and drawing presses is described. It is considered to be particularly suitable for forging presses as the entire operation can be performed automatically. Details of the equipment used for this type of control are given.—B. G. B.

The Hydraulics of Presses. A. Buzas. (*Maschinenwelt u. Elektrotechnik*, 1954, **9**, July, 188–190). Types of presses, and the factors governing their selection for various purposes are discussed. The properties of suitable hydraulic oils and methods of cleaning oil are indicated.—L. D. H.

Hydraulic Accumulators for Heavy-Press Operation. A. F. Welsh. (*Mech. Eng.*, 1954, **76**, July, 571–574, 581). A brief history is given of the development of hydraulic accumulators. Of the three basic types, weighted, air piston, and air bottle, the last is discussed in detail. The accumulator systems as applied to specific presses in the U.S. Air Force Heavy Press Program are described.—D. H.

New Cold Forming Process Saves Time and Material. C. L. Sporck. (*Product Eng.*, 1954, **25**, June, 186–189). The "Flowturn" process is a combination of roll forming and spinning which can produce parts difficult or impractical to make by deep drawing. The metal from a blank is squeezed between a roll and a mandrel and is displaced by plastic deformation as the roll advances, extending the length of the blank until the workpiece is formed to the shape determined by the mandrel. Materials that can be worked range from soft aluminium to high tensile stainless steels.—A. M. F.

The Manufacture of Small-Diameter and Other Special Precision Tubes. (Machinery, 1954, **84**, Mar. 19, 575–585). Manufacturing processes at the works of Accles & Pollock Ltd., Oldbury, where small steel tubes for instruments, Bourdon gauges are drawn, are described. Tubes with external diameters down to 0·0017 in. as well as multi-base tubes are made.—R. A. R.

ROLLING-MILL PRACTICE

Calculating the Power Requirements for Rolling Sections. A. Geleji. (*Acta Technica*, 1954, **9**, (1–2), 203–212). [In German]. The power required to roll sections consists of two components, that needed for shaping and that consumed by friction. The former depends on the draught, the mean resistance to deformation, and the speed of rolling; the latter depends on the slip between the roll surface and the section, the coefficient of friction, and the rolling pressure. Formulæ for calculating power requirements are derived.

Calculation of Roll Pressures. A. Vach. (*Hutnické Listy*, 1954, **9**, (7), 399–403). [In Czech]. Formulæ are derived for the calculation of roll pressures and torques acting on the rolls, taking into account friction and the speed and temperature dependence of the resistance of the metal to plastic deformation.—P. F.

The Effects of Screw and Speed Setting Changes on Gauge, Speed, and Tension in Tandem Mills. W. C. F. Hessenberg and W. N. Jenkins. (*Research*, 1954, **7**, Aug., s45). A method is outlined whereby the influence of alterations in the screw or speed setting of any stand in a tandem arrangement on the behaviour at other stands may be calculated. It is based on consideration of the volume flow rate in the system, and requires knowledge of the roll torque.—K. E. J.

Steel Rolling-Mill Drives. (*Brit. Eng.*, 1954, **37**, Sept. 95–96). Details are given of two recent installations. One, by British Thomson Houston Co., Ltd., is the electrical drive for a 10 in. finishing bar mill, consisting of five stands, three

having 3-high rolls. The English Electric Co. supplied the electrical equipment for the first planetary mill to be put into operation, to reduce 1¾ in. slabs to strip; it has pinch, feed, planetary, and finishing rolls.—K. E. J.

Rolls—Their Quality and Uses. K. H. Wright. (*Iron Coal Trades Rev.*, 1954, **169,** Sept. 5, 571–577). The author shows diagrammatically the ranges of cast-iron and steel rolls at present available, and discusses the properties and uses of the main types with details of their manufacture. The relative merits of forged steel and chilled alloy iron rolls are summarized, and mention is made of the possibilities of spheroidal graphite cast iron rolls. Reference is also made to testing and inspection.—G. F.

The Advantages of Taper Roller Bearings Applied to Roll Necks. W. P. Snedden. (International Symposium on Lubrication, Liège, 1954, *Rev. Univ. Min.*, 1954, 9th series, **10;** June, 242–249). The fundamental principles of the use of tapered roller bearings are first explained. The application of these bearings on rolling mills is described and since the time for changing rolls is short (15–20 min.) the economic advantages of these bearings on modern high-speed mills are considerable. The different types of roller bearings which are available are described.—B. G. B.

The Use of Synthetic Resin Bearings in Rolling Mills. J. Diverse. (International Symposium on Lubrication, Liège, 1954, *Rev. Univ. Min.*, 1954, 9th series, **10,** June, 282–296). Methods of making synthetic resin bearings are described and the properties of these materials are compared with those of bronze. The use of synthetic resin bearings in rolling mills is discussed and precautions which must be taken are explained.—B. G. B.

Economic Modernization of Rolling Mills. (*Echo Mines*, 1954, June, 385–387). A short illustrated account of the mechanization of a hand operated rolling mill is given. The mill was used for the rolling of 400-kg. blooms. It required five operators four of whom were not necessary after mechanization, while the output increased by 120%.—B. G. B.

Principles of Calibrating Continuous Rolling Mills and the Calculation of Rolling Speed. Z. Wusatowsky. (*Met. u. Giesserei Techn.*, 1954, **4,** July, 308–310). Formulæ are developed for calculating the rolling speeds for flat bars and for rolling with symmetrical passes; and some examples of their application are given.—R. A. R.

Graphical Determination of the Dimensions of the Stock and Subsequent Roll Passes for Cold Rolling. Z. Wusatowski. (*Biuletyn Informacyjny*, **5,** (6), 21–23; *Hutnik* (Poland), 1954, **21,** (6)). [In Polish]. A graph for the calculation of dimension of the stock, subsequent roll passes, and finished product, for the cold rolling of strips and sheet is given.—V. G.

Breakdowns of Rolling-Mill Drives. L. Tarnowski. (*Hutnik* (Poland), 1954, **21,** (6), 180–183). [In Polish]. Some examples of breakdowns of direct and alternating-current rolling mill drives are given and the preventative methods used in a Russian works are described.—V. G.

Scale Removal by High Pressure Water. Z. Polek. (*Hutnik* (Poland), 1954, **21,** (6), 172–176). [In Polish]. Methods of scale removal during rolling are outlined and a description of a new installation for the removal of scale by high-pressure water in a Polish rolling mill is given.—V. G.

The Problems of Rolling Flat Products. A. G. Lefebvre. (*Soc. Roy. Belge. Ing.*, 1954, Jan., 3–47). A comprehensive account of rolling-mill operation for the production of strip, sheet, plate, and tinplate is given. Different methods of rolling are considered and these include hot and cold rolling, continuous, semi-continuous, the Steckel reversible and the Sendzimir planetary mills. The manufacture of tinplate by the electrolytic method and continuous galvanizing are also considered. The uses to which the products are put are discussed. A number of line diagrams and photographs of the equipment used are shown. A summary of the characteristics and performance of 61 rolling mills in use in 15 countries is given in tabular form.—B. G. B.

Mile a Minute Rod Mill. D. L. Siegelin. (*Blast Furn. Steel Plant*, 1954, **42,** Aug., 928–933). A description of the Continental Steel Corporation's No. 2 rod mill at Kokomo, Indiana, is given. The mill is capable of producing rods from 0·218 to 1·125 in. in dia. Billets 30 to 32 ft. in length and either 2, 2½ or 2½ in. square are used.—B. G. B.

Oval-Square Roughing Down. M. Petitfrére. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1954, (5), 933–954). The need to avoid excessive pressures when roughing down is stressed. Rolling techniques and roll pass design for non-continuous and continuous oval-square mills are described. An appendix gives tables for the calculation of the design of oval roll passes.—A. G.

Reconstruction of a 550-mm. Cross-Country Mill Train by the Addition of a Continuous Mill for Rolling Hot Strip and Tube Skelp. H. Müller. (*Stahl u. Eisen*, 1954, **74,** Aug. 26, 1132–1136). In order to increase the size of rolled strip from 192 × 3·0 mm. to 278 × 3·5 mm. an existing mill at the Mannesmann works, Duisburg-Huckingen, was modified, fitted with a new pusher furnace, and supplemented with a fully continuous four-high tandem finishing mill. The plant, its operation and control are described.—J. P.

Cold-Strip Mill Plant Designed for Large Range of Widths and Gauges : New Installation at Newport Works of Whitehead Iron and Steel Company, Limited. (*Iron Coal Trades Rev.*, 1954, **169,** Aug. 27, 521–523). A detailed description is given of the new cold-strip mill plant and its auxiliary equipment at the Newport works of the Whitehead Iron & Steel Co. Ltd. The plant consists of a four-stand four-high tandem mill, with a finishing speed of 2100 ft./min., and a single-stand four-high skin-pass mill. The plant is designed to handle a wide range of gauges and widths of strip.—G. F.

Starting Up an Automatic Repeating Hoop Mill : New Mill at the Barrow Steel Works, Limited. D. W. Ainsbury. (*Iron Coal Trades Rev.*, 1954, **169,** Sept. 3, 581–583, 580). The author describes the layout and operation of an automatic repeating hoop mill recently installed at Barrow Steel Works Ltd., and discusses some of the problems encountered in starting up the installation.—G. F.

Studies on the Relationships between the Seams of Round Billets and the Outside Cracks of Tube Blanks Pierced by the Stiefel-Mannesmann Piercing Mill. K. Inouye and T. Soyejima. (*Tetsu to Hagane*, 1952, **38,** May, 301–305). [In Japanese]. Cracks on the outside of hollowed pieces are due to surface seams; their harmfulness depends on the seam depth and not on the type of seam.—K. E. J.

Studies on the Piercing Process of Seamless Steel Tube by the Stiefel-Mannesmann Piercing Mill. K. Inoue and M. Kato. (*Tetsu to Hagane*, 1952, **38,** June, 383–388; Dec., 992–997). [In Japanese]. Tests were made on the effect of altering the inclined angle on the deformation, reduction, cracking, and speeds of the process. Increases up to 9° reduced the power requirements.—K. E. J.

MACHINERY FOR IRON AND STEEL PLANT

Possibilities of Using Gas Turbines in Power Stations and in Industry. A. Pineau. (*Chaleur et Ind.*, 1954, **35,** July, 189–197; Aug., 231–238). Various open and closed circuit gas turbine cycles are discussed. The use of gas turbines for blast-furnace blowing is described, and three cycles are illustrated. Two of these retain the Cowper stove for blast heating, but generate additional electric power from the top gas by means of the gas turbine which also supplies the blast. In the third cycle, the gas turbine provides the hot blast by means of a recuperator which utilizes the gas turbine exhaust gases to heat part of the air from the compressor. Other cycles are proposed in which gas and steam turbines are combined in a single power generating installation, or in which the gas turbine method is applied to a steam turbine system. They have each been proposed for 100,000-kW. power stations. Steam and gas turbine performances are compared.—T. E. D.

Gas Turbines and Their Present Applications. P. Chambadal (*Usine Nouvelle*, 1954, Spring Issue, 119–121). Several types of cycle for industrial gas turbine installations are described and explained with examples of existing plants. Among those mentioned are the Brown-Boveri turbine and gas compressor installed in a Spanish works for blowing converters, and in the Dudelange Steelworks, Luxembourg, for blowing converters or blast-furnaces. In each case blast-furnace gas is used for fuel but liquid fuel may be used as an alternative. The Luxembourg plant includes a 5400-kW. generator which only operates to capacity when air is not being blown, and falls to zero when air is being blown at 15 kg./sec. at 2·2–3 kg./sq. cm. absolute.—T. E. D.

Variable Speed Coupling: Examples of Applications in Industry. (*Iron Steel*, 1954, **27,** July, 349–350, 376). Brief details are given of the construction and operation of the "Heenan-Dynamatic" variable-speed coupling, and examples

of its application in industry are described. These include its use in a continuous high-speed production casting line at West Yorkshire Foundries, Ltd., and in strip-slitting machines at Samuel Fox & Co. Ltd.—G. F.

The Standardization of Steelworks Auxiliary Motors. C. F. R. Fielden and J. H. Messenger. (*Iron Steel*, 1954, **27**, July, 346–348). The authors discuss the advantages to be gained by the standardization of frame sizes and ratings of steelworks auxiliary motors, and describe the new standard "MDX" motor and the considerations underlying its design and use. Both the mechanical construction and the electrical design are dealt with in detail.—G. F.

LUBRICANTS AND LUBRICATION

New Method for the Determination of Lubricating Value. A. Maman. (*Recherche Aéronaut.*, 1954, Jan.-Feb., 33–37). After presenting the difficulties involved, the apparatus is described and results are given and discussed. The method employs a chain, in which stainless steel spheres are embedded as reproducible points of contact, in contact with a moving cylinder.—T. E. D.

Tests on this Wire Rope Fatigue Machine Proved that Lubricants Do Penetrate Wire Rope. W. I. Lex. (*Eng. Min. J.*, 1954, **155**, June, 96–98). Exhaustive tests demonstrated the value of correct external lubrication for ropes. The fibres are preserved longer, corrosion is retarded, friction is reduced, the onset of fatigue is delayed, and the lives of the ropes, drums, and sheaves are prolonged.—K. E. J.

A Rational Solution to Friction Problems. F. Colomb. (*Usine Nouvelle*, 1954, Spring Issue, 277–279). Results of tests on a product inverted by C. Wynn in the U.S.A. are given. The product, put on the American market in 1946, is sold as a solution in heavy oil, to be used as an additive to lubricants. It operates by means of a chemical-metallurgical concentration process at the metal surface.—T. E. D.

Hydrodynamic Lubrication of Roller Bearings. W. Lewicki. (*Engineer*, 1954, **197**, June 25, 920–922). The classical theory of viscous flow is applied to elastically deformed surfaces in order to establish physical criteria for the exist nce of fluid wedge lubrication in the cylindrical roller bearing. Approximate laws of rolling friction are deduced in terms of fundamental units. (12 references).—M. D. J. B.

International Conference on Lubrication. (*Rev. Univ. Min.*, 1954, Series 9, **10**, June, 157–412). This Conference, organized by l'Association des Ingénieurs, was held at Liège on May 6–8, 1954. The papers of interest to the iron and steel industry were:

Introduction. C. Hanocq. (157–168).

Judging Lubricants by Their Performance. J. Groff. (168–189).

Methods of Research and Mechanical Testing Used in the Socony-Vacuum Laboratories. R. B. Killingsworth, C. W. Nicols, jun., and J. F. Socolofsky. (190–206).

Examination of the Structure of Lubricating Oils. G. Souillard. (213–220).

Interpretation of the Results of Laboratory Tests on Lubricants. R. Lacourt. (220–226).

Machining Lubricants. H. L. Bingham. (226–242).

The Advantages of Taper Roller Bearings Applied to Roll Necks. W. P. Snedden. (242–249). [See p. 293]

Some Points of View on the Lubrication of Roller Bearings. L. Berner. (296–306).

WELDING AND FLAME-CUTTING

The Metallurgy of Welding. W. I. Pumphrey. (*Metallurgia*, 1954, **50**, July, 3–9). The metallurgical changes taking place during welding and their effect on the properties of the weld metal and the heat-affected zone of the parent metal are reviewed. Fusion welding either by gas or electric arc, is principally discussed and the use of low hydrogen electrodes, the formation of the sigma phase, and intergranular corrosion are considered.—B. G. B.

High-Speed Motion Picture Photography Applied to Resistance Welding. I. S. Goodman. (*Welding J.*, 1954, **33**, June, 548–552). A brief history of high-speed motion picture photography has been presented. The ability to apply this technique to several different resistance welding and testing problems has been demonstrated.—U. E.

Research of Welding Arc. M. Ozawa, and T. Morita (*Welding J.*, 1954, **33**, June, 280s–284s). This is a mathematical treatment of the characteristics of the welding arc.—U. E.

Welding of Heat Resisting and Corrosion Steels. J. A. McWilliam. (*Engineer Foundryman*, 1954, **11**, May, 66–71). The welding characteristics of the steels are briefly discussed with reference to plant fabricated from these materials.

Consumable Insert Method of Root Pass Welding. T. A. Risch and A. E. Dohna. (*Welding J.*, 1954, **33**, July, 670–679). A description is given of a new method of butt welding plates or pipes without the use of backing rings or bars. The method facilitates manipulation by the operator of an inert-gas-welded tungsten arc torch to fuse to the parent metal a filler rod of controlled dimensions and composition which is inserted between the root faces of the butt joint. This technique gives a smooth crevice-free reinforcement weld surface on the far side of the joint in all positions of welding.

Welding in Argon Atmosphere with Refractory and with Expendable Electrodes. E. Sellier. (*Rev. Soudure*, 1954, **10**, (1), 3–21). After reviewing developments in the uses of protective atmospheres in electric arc welding, the author discusses the properties and manufacture of argon and gives a detailed account of welding procedure in argon atmosphere. The Heliarc and Sigma methods are described as well as welding equipment and electrodes. The possibilities of semi- and fully automatic welding are examined together with the fields of application for both methods.—M. D. J. B.

How to Solder Stainless Steel: Weld Stainless Steel (*Steel*, 1954, **134**, May 31, 108–110). Points to observe when soldering or welding stainless steel are noted.—D. L. C. P.

Dissimilar Metals Can Be Flash Welded. L. F. Spencer. (*Steel*, 1954, **134**, June 28, 132–133). Considerations for welding two dissimilar metals are noted. In particular the operation of an automatic welder for joining a high temperature alloy to steel for exhaust-valves, is described.—D. L. C. P.

Study of the Cooling Rates in Flash Welds in Steel. E. F. Nippes, W. F. Savage, G. Grotke and P. M. Robelotto. (*Welding J.*, 1954, **33**, July, 339s–362s). An extensive study was made of weld-centreline rates of cooling at 1300, 1000, and 900° F., depending on three welding variables: the rate of platen acceleration, final clamping distance, and thickness of the material, for flash welds employing parabolic flashing patterns. Flash welding variables resulted in weld-centreline cooling rates at 1300° F. ranging from 40° F./sec. to 365° F./sec. The formation of considerable amounts of martensite at the weld line could not be avoided with the Cr–Mo and Ni–Cr–Mo steels investigated. Micrographs and the results of hardness and tensile test are presented and discussed to relate weld properties and weld-zone microstructures.—U. E.

Notes on the Welding of 12–14% Austenitic Manganese Steels. (*Welder*, 1954, **23**, Jan.-Mar., 137–138). The welding of manganese steel (*e.g.*, C 1·0–1·4, Mn 10–14%) and nickel manganese steel (*e.g.*, C 1%, Ni 3%, Mn 12%) is described with notes on the heat-treatment and precautions to prevent cracking.—U. E.

Metallic Arc Welding of Spheroidal Graphite Cast Iron. F. A. Ball and D. R. Thorneycroft. (*Inst. Brit. Found.*, 1954, June 22–25, *Paper No.* 1095). Detailed results are presented of tests made on welded spheroidal graphite cast iron using nickel-iron and aluminium-bronze electrodes. Mechanical and machining tests were carried out on the butt-welded joints and a comprehensive metallographic study was made of the weld metal and the adjacent cast iron.—B. C. W.

Arc Welding by the Nertalic-Aircomatic Process. J. Brillié. (*Rev. Sondure*, 1954, **10**, (1), 22–32). The author reviews the development of welding in argon atmospheres since 1926. Details are given of the Nertolic-Aircomatic method of welding, which consists of transferring the weld metal by pulverization. Research techniques for developing the method make extensive use of cinematography which make it possible to follow the trajectory of the droplets, the behaviour of the electrode, and the formation of the weld crater. Details are given of all welding apparatus including the power-feed unit, the argon supply unit, the manual welding pistol grip and the automatic welding equipment. Applications of the process to the welding of stainless steels are discussed.

The Plurial Process. M. Lebrun. (*Welding and Metal Fab.*, 1954, **22**, June, 228–231). The author explains the development and principles of the Plurial process which has been used in France, chiefly for hard-facing. In this process bundles of electrodes are used instead of one of large diameter

for surfacing of rails. Electrical characteristics of these electrode bundles are discussed together with quality of the weld deposits. Possibilities of using both mild steel and alloy steel electrodes in one bundle are briefly indicated.—U. E.

A New Method of Testing the Soundness of Spot Welds in Low-Alloy Semi-Hard Steels. P. Journat. (*Rev. Soudure* 1954, **10**, (2), 100–104). The author describes a new method of testing spot welds by applying shear by torsion to two small test pieces spot welded together. The method consists simply of fixing one of the pieces in a vice and applying a measured torque to the other piece. Results of tests are described, photographs are presented showing the quality of the spot welds. The method makes it possible to relate welding techniques to the quality of the welds.

Effect of Thermal Activation on Fatigue Life of Butt Welds. A. M. Freudenthal and R. A. Heller. (*Welding J.*, 1954, **33**, July, 327s–338s). The effect of rest periods at moderately elevated temperatures on the fatigue life of butt-welded mild steel specimens is investigated. For mild steel, the Unionmelt process produces butt welds of longer mean fatigue life than that of the unwelded metal.—U. E.

Exploratory Tests of the Air-Carbon Arc Cutting Process. A. R. Hard. (*Welding J.*, 1954, **33**, June, 261s–264s). The Arcair metal-cutting process is described. In this method an arc is drawn between a carbon electrode and the work. Two jets of compressed air coming from one clamping jaw of the electrode holder are directed axially along the electrode and remove parent metal as it is melted by the arc.—U. E.

Iron Powder Coatings—Electrode Design Matches Advance Billing. J. Hinkel. (*Steel*, 1954, **135**, July 19, 104–105). After a year's commercial application in the U.S.A., it is reported that heavily coated electrodes containing large quantities of powdered iron in their coatings give lower welding costs through higher welding speeds and reduced cleaning requirements. Characteristics of the technique are described.— D. L. C. P.

Adhesive Bonding Complements Soldering and Brazing. H. H. Simons. (*Welding J.*, 1954, **33**, July, 647–650). Different types of adhesives, their characteristics and the principles of adhesive bonding are discussed. A comparison is made with other joining methods, such as brazing and soldering.—U. E.

The Application of Oxygen-Using Processes in Engineering. R. E. Doré. (*Trans. Inst. Marine Eng.*, 1954, **66**, Aug., Supplement 5–9). A general survey is made of the uses of oxygen in engineering, and data are presented on the consumption of oxygen and acetylene when cutting steel plate ½, 1, 2, and 4 in. thick. Curves showing the increase in consumption with decreasing impurity of the oxygen are also shown.
R. A. R.

Flame Cutting with Electronic and Magnetic Tracers. R. F. Heimkamp. (*Canad. Metals*, 1954, **17**, June, 46–54). An account of the application of magnetic and electronic devices for the control of flame-cutters is presented. Details are given of their performance and of the design and use of templates. Particular attention is paid to the electronic tracer which is extremely versatile; the template required is very cheap.—B. G. B.

The Repair of Chill-Cast Iron Rolls by Welding. H. Becker. (*Stahl u. Eisen*, 1954, **74**, Aug. 26, 1136–1140). The use of ferritic welding material of great hardness is not satisfactory for repairing cracked cast-iron rolls. The best material is one which has a surface hardness similar to that of the roll itself yet includes an intermediate layer which keeps the change of hardness in the transition zone to a minimum, and which has the property of taking up shrinkage by plastic deformation and so preventing crack formation. Tests have shown that the normal welding techniques are not satisfactory, but that austenitic welding materials offer promising possibilities.—J. P.

The Repair of Grey and Chill-Cast Iron Rolls by Welding. K. Scholl. (*Stahl u. Eisen*, 1954, **74**, Aug. 26, 1142–1144). The methods employed for repairing the body and necks of rolls by welding and their economic advantages are briefly discussed.—J. P.

Refacing Steel Rolls by Welding. H. Becker. (*Stahl u. Eisen*, 1954, **74**, Aug. 26, 1144–1156). The problems associated with the refacing of steel rolls by welding are discussed. An extensive investigation of the powder welding process applied to a number of discarded rolls has shown that favourable results can be obtained by this method, but great care must be taken in all the stages of the work. Further research is still necessary to develop a fully satisfactory procedure.

Maintenance and Welding in the Steelworks F. W. Griese. (*Stahl u. Eisen*, 1954, **74**, Aug. 26, 1162–1168). The various methods described in the literature for repairing components (main y rolls and roll necks) by rod and powder welding processes are reviewed. (16 references).—J. P.

Oxygen and Powder Cutting R. S. Babcock. (*Rev. Soudure*, 1954, **10**, (2), 79–85). The author discusses the chemical processes of oxygen and iron powder cutting and describes in some detail the equipment and techniques to be used with these two methods. The metallurgical and engineering aspects of the processes are examined and their uses in iron foundries and for cutting non-ferrous metals, slags, and carbon steels are discussed.—M. D. J. B.

Contribution to the Study of Oxygen Cutting J. M. Morelle. (*Rev. Soudure*, 1954, **10**, (2), 105–118). An account is given of work carried out on oxygen cutting at Louvain University, on behalf of the Institut Belge de la Soudure. The techniques and possibilities of the method are described and data on oxygen consumption and pressure, speed and thickness of cut, quality of cut and description of equipment are presented.—M. D. J. B.

MACHINING AND MACHINABILITY

Study on High-Speed Tools. H. Hotta. (*Tetsu to Hagane*, 1952, **38**, Jan., 25–31; May, 333–336; Dec., 1020–1035). [In Japanese]. Studies were made of methods of utilizing waste material from high-speed steels, *e.g.*, making tool tips with welding electrodes made from turnings, and re-use of broken pieces. The influence of various heat-treatments on the torsional impact value of 18/4/1 W–Cr–V steel was investigated, and the influences of carbon, chromium, tungsten, and vanadium on several properties of this steel were determined. A new method of connecting the tool tip to the shank is described; this is satisfactory even for heavy cuts with strong vibration. (39 references).—K. E. J.

CLEANING AND PICKLING

Barrel Finishing Operations on Accounting Machine Components (*Machinery*, 1954, **85**, July 9, 55–61). The cleaning and finishing of small parts for accounting machines at the works of Powers-Samas Accounting Machines, Ltd., are described. The parts first pass through a Dawson washer and eventually reach the Roto-Finish rubber-lined octagonal barrels into which batches are loaded together with grinding chips and water.—R. A. R.

Cathodic Vacuum Etching. T. R. Padden and F. M. Cain, jun. (*Metal Progress*, 1954, **66**, July, 108–112, 162–164). A description of the equipment and procedure is given. The time for etching is of the order of 1 to 3 min. A number of optical and electron photomicrographs of specimens etched by this technique are shown.—B. G. B.

Electromachining and Superfinishing as a Production Tool. I—The Process and Its Applications. A. T. Steer. (*Electroplating*, 1954, **7**, July, 249–255). The process of electropolishing is described and electrolytes for treating steels and non-ferrous alloys are listed. The process can be used for the controlled removal of metal from ground or emery bobbed surfaces to give a mirror-like finish without causing work hardening of the surface layer.—A. D. H.

Radioactive Tracers in Metal Pre-Treatment. (*Corrosion Prevention and Control*, 1954, **1**, May, 148–152, 162; June, 224–227). The progress in the use of artificially produced radioactive materials in investigations concerned with the pre-treatment of metals is reviewed. The general considerations involved in such studies are indicated and the results of various metal clearing tests, in which a soil containing radioactive carbon was used, are described.—L. E. W.

Notes on Cleaning Cycles for Plating. A. K. Graham. (*Trans. Inst. Metal Finishing*, 1954, **31**, Advance Copy No. 17). Cleaning procedures suitable for steel and other surfaces before nickel plating are given. A peeling adhesion test is described.—A. D. H.

Electrolytic Derusting—Principles and Applications of the Process. L. Kenworthy and T. F. East. (*Engineering*, 1954, **178**, Aug. 20, 235–237). The authors describe the electrolytic cleaning process with particular reference to its application by the Admiralty to corrosion problems in the Royal Navy.—M. D. J. B.

PROTECTIVE COATINGS

Metal Finishing in Italy. F. Enrico. (*Product Finishing*, 1954, **7**, May, 52–61). The author reviews developments in metal plating during recent years and describes installations at the Rizzato works (Padua), Carello works (Turin), Coffaratti works (Milan), and Fiat works (Turin).—R. A. R.

On the Experimental Methods for the Determination of Electrode Polarization. R. Piontelli. (*Trans. Inst. Metal Finishing* 1954, **31**, Advance Copy No. 5). The systematic errors introduced in the use of the Luggin-Haber capillary are eliminated in the new electrode arrangements proposed.

Unsolved Problems in the Metal Finishing Industry. W. L. Pinner. (*Trans. Inst. Metal Finishing*, 1954, **31**, Advance Copy, No. 28).

Barrel Plating Electrolytes. E. E. Halls. (*Product Finishing*, 1954, **7**, Apr., 72–118). An account is given of experiments investigating the operating characteristics of electrolytes for zinc, nickel, cadmium, silver, and gold barrel plating.

Application of Radioactive Tracers to the Knowledge of Partial Intensity in Electrolysis. R. Audubert, Jeanne Pérans, and Thérèse Mallet. (*Comptes Rendus*, 1954, **238**, May 10, 1881–1883).

Voltage and Current Fluctuations in the Output of Plating Rectifiers. V. L. Richards. (*Plating*, 1954, **41**, July, 773–781).

Thermostatic Control in Electroplating. L. Walter. (*Electroplating*, 1954, **7**, June, 212–214). Factors governing the accuracy and method of control of plating vats are discussed.

Depreciation and Maintenance of Metal Finishing Plant. III—The Percentage Method of Computing Depreciation of Plant. S. H. Withey. (*Electroplating*, 1954, **7**, July, 263–265). An example is presented of a method of arriving at the annual depreciation applicable to plating plant.—R. A. R.

Plastics in the Plating Shop. I—Plating Shop Floors. II—Tanks and Vessels. III—Fume Extraction and Pipelines. IV—Containers and Coatings. (*Product Finishing*, 1954, **7**, May, 62–68, 142; June, 88–92; July, 68–74, 124; Aug., 81–83, 122, 124).

Something About Metal Colouring. A. Wogrinz. (*Maschinenwelt. u. Elektrotechnic*, 1954, **9**, July, 194–196). A survey is given of processes by which coloured protective surfaces are produced on metals by chemical processes.—L. D. H.

Plating in the Automotive Industry: Its History and Development. W. M. Phillips. (*Metal Finishing*, 1954, **52**, July, 60–65; Aug., 73–77; Sept., 76–79, 85).

Waste Purification—Plater Profits Two Ways. A. J. D'Orazio. (*Steel*, 1954, **135**, July 19, 130–131). The methods used in a large plating department to prevent pollution by waste disposal, and to reclaim metals from chromic acid, acid nickel, and acid copper plating solution rinse tanks are described. Particulars are given of the method of removing contaminating metals from the chromic acid washings by ion exchange, and concentrating the chromic solution for re-use.—D. L. C. P.

Simplified Waste Treatment Methods for the Electroplating Industry. L. E. Lancy. (*Metal Finishing*, 1954, **52**, July, 66–71).

Corrosion Prevention by Spray Packaging. D. W. Harbour. (*Corrosion Prevention and Control*, 1954, **1**, July, 288–291, 295). The author describes the methods and products developed by R. A. Brand and Co. Ltd., for both 'sealed envelope' and 'strippable film' techniques in the spray packaging anti-corrosion process.—L. E. W.

Applications of Conveyors. E. E. Halls. (*Product Finishing*, 1954, **7**, May, 71–140). Systems using conveyors in plating and enamelling shops are discussed generally.

A Graphical Method for Rapid Estimation of the Thickness of Evaporated Metal Films. K. P. Nandy. (*Rev. Sci. Instruments*, 1954, **25**, May, 523–524). The theory and construction of a graph, drawn on linear paper, for the rapid estimation of the thickness of metal films evaporated under varying conditions is given.—L. D. B.

The Cause of Stress in Evaporated Metal Films. R. W. Hoffman, R. D. Daniels, and E. C. Crittenden, jun. (*Proc. Phys. Soc.*, 1954, **B67**, June 1, 497–500). Work on metal films condensed from the vapour indicates that the intrinsic stress is the result of the history of its imperfections, including the crystal boundaries. The total stress usually includes a component resulting from differential expansion. Experimental results are given for iron, nickel, copper, and cobalt.

A Quantitative Adhesion Test for Electro-Deposited Chromium. C. Williams and R. A. F. Hammond. (*Trans. Inst. Metal Finishing*, 1954, **31**, Advance Copy No. 9). The development of a mechanical adhesion test is described and its application to experimental studies of factors affecting the adhesion of chromium deposits is studied.—A. D. H.

The Influence of Annealing on the Structure and Hardness of Electrodeposited Chromium. C. P. Brittain and G. C. Smith. (*Trans. Inst. Met. Finishing*, 1954, **31**, Advance Copy No. 10).

Radiometric Study of the Chromium Sulfate Complex Formed in Chromium Plating Baths. R. L. Sass and S. L. Eisler. (*Plating*, 1954, **41**, May, 497–501).

Notes on the Gaseous Chromizing of Steel. P. R. Duré (Symposium on Heat Treatment, Liège, 1954; *Rev. Univ. Min.*, 1954, 9th series, **10**, July, 531–541). An historical survey of this process is made and a description of a furnace and ancillary equipment for chromizing is given. Examples of the results obtained are shown.—B. G. B.

The Prevention of Cracking in Nickel Electrodeposits. T. E. Such. (*Trans. Inst. Met. Finishing*, 1954, **31**, Advance Copy No. 13).

The Weathering of Nickel/Chromium Electrodeposits. W. A. Wesley and B. B. Knapp. (*Trans. Inst. Met. Finishing*, 1954, **31**, Advance Copy No. 18).

Kanigen Nickel Plating. G. Gutzeit. (*Metal Progress*, 1954, **66**, July, 113–120, 146). A detailed account of this process, which uses a solution containing hypophosphite ions and nickel ions for nickel coating base metals and requires no electric current, is given. The equipment required for the process is described. The method is particularly suitable for objects of irregular shape and made from ferrous alloys, copper, brass, bronze, or aluminium.—B. G. B.

Bright Nickel Process Simplifies Bumper Manufacture. R. D. Miller. (*Products Finishing*, 1954, **18**, June, 24–32). A process which includes a final bright nickel plating cycle before a light buffing operation is described.

Special Property Nickel Plate. (*Steel*, 1954, **134**, June 21, 135). The method of electroplating using nickel sulphonate with bath additions, and the properties of the nickel deposits are described. The hardness of the coating approaches 600 Vickers and internal stresses are low.—D. L. C. P.

New Ideas for Galvanizing and Patenting Frames. N. Davidson. (*Wire Ind.*, 1954, **21**, Aug., 809–810). The author explains how the 'gravity block,' developed by Sir James Farmer Norton and Co. Ltd., can be applied to strand galvanizing plant so as to reduce the handling of wire and manning of the plant. Suggested layouts are described.

Probable Tendency in the Future Utilization of Zinc for Galvanizing. M. Souske. (*Usine Nouvelle*, 1954, Spring Issue, 217–221). Experiments were performed to investigate the effects on galvanization of impurities present in zinc of the quality normally used. Impurities investigated were lead, iron, tin, cadmium, copper, antimony and aluminium. The influence of varying amounts on the weight of zinc deposited under controlled conditions was studied.—T. E. D.

Structure of Zinc Coatings Assessed from Electrochemical Dissolution. W. Katz. (*Arch. Eisenhüttenwesen*, 1954, **25**, July-Aug., 307–314). The individual layers of zinc coatings on steel exhibit, on anodic polarization in NaCl-$ZnSO_4$ solution, increasingly noble potential as their iron content rises. By following the time-potential curve during electrochemical dissolution, the thickness of the layers may be determined with an accuracy as great as that obtained by metallographic examination, and the drawbacks of the Preece test avoided. The method is particularly suitable for the determination of the thickness of thin wiped layers on galvanized wires and it may also be used to indicate the galvanizing process employed.—J. P.

An Economic Analysis of the Comparative Merits of Gas, Coke-Oven Gas, and Electricity for Heating Galvanizing Kettles. K. Janecký. (*Hutnik*, (Prague), 1954, **4**, (7), 216–218). [In Czech].

Research Work on the Galvanizing of Kitchen Utensils. A. Gordet. (*Mét. Constr. Mécan.*, 1954, **86**, Feb., 129–131; Apr., 337–339). The types of kitchen utensils which are galvanized are considered in relation to their ease or otherwise of treatment. The efficiency of zinc plating processes are considered and factors controlling the production of sound coats of zinc are reviewed.—B. G. B.

Zinc Plating Propeller Blades. C. B. Conwell and C. J. Stansfield. (*Product Finishing*, 1954, **7**, July, 86–91). **Propeller Blades Zinc Plated Automatically.** C. B. Conwell and C. J. Stansfield. (*Products Finishing*, 1954, **18**, May, 54–60). The layout of the plating installation is described. Special features include recycling of the blades through the zinc plating tank, simplified solution control, conservation of spray-rinse water and special handling equipment.—A. D. H.

Concerning the Copper-Sulphate Test of the Uniformity of Galvanized Coatings on Steel Wires. G. Schikorr. (*Draht, German ed.*, 1954, **5**, June, 217–219). An investigation of the reliability of the copper sulphate test is described and changes in the testing procedure prevalent in Germany are recommended.—J. G. W.

Recent Progress in Hot Dip Galvanizing. R. L. Stubbs. (*International Conf. on Hot Dip Galvanizing*, 1954, *Oxford Conf. Preprint, No.* 1: Zinc Dev. Assoc.). Progress in general and specialist galvanizing in Great Britain is reported. Recent developments include the hot dip galvanizing of structural steel and metal windows, and the complete galvanizing of railway goods wagons.—A. G.

The Inspection of Galvanized Structural Steelwork. W. R. Thompson. (*International Conf. on Hot Dip Galvanizing*, 1954, *Oxford Conf. Preprint No.* 2: Zinc Dev. Assoc.). Information is given to assist the purchaser to assess by tests and visual examination the quality of a galvanized product. Advice is also given on the treatment of galvanized steelwork during storage before erection.—A. G.

After Treatments for Galvanized Steel. W. L. Hall. (*International Conf. on Hot Dip Galvanizing*, 1954, *Oxford Conf. Preprint No.* 3: Zinc Dev. Assoc.). White deposits may form wherever water penetrates between zinc surfaces in contact. Storage precautions and various surface coatings such as chromatizing and painting are discussed. The problem of protection against underground corrosion is also considered.—A. G.

Cost Finding for Job Galvanizing. J. H. Mayberry. (*International Conf. on Hot Dip Galvanizing*, 1954, *Oxford Conf. Preprint No.* 4: Zinc Dev. Assoc.).

Some Aspects of Cost Estimating in General Galvanizing. L. F. Chambers. (*International Conf. on Hot Dip Galvanizing*, 1954, *Oxford Conf. Preprint No.* 5: Zinc Dev. Assoc.).

The Development of Continuous Galvanizing in the United States. N. E. Cook. (*International Conf. on Hot Dip Galvanizing*, 1954, *Oxford Conf. Preprint No.* 6: Zinc Dev. Assoc.). Continuous galvanizing has developed rapidly in America due to the high cost of labour and the large market for galvanized products. The most recent process is that due to Cook-Norteman in which aluminium is dispersed in the zinc bath by induction stirring. Details and advantages of the method are given.—A. G.

The Occurrence of Faults in Galvanized Sheet. H. Wiester and D. Hortsmann. (*International Conf. on Hot Dip Galvanizing*, 1954, *Oxford Conf. Preprint No.* 7: Zinc Dev. Assoc.). The results of research on flaws in galvanized sheets and their causes are briefly reported. Faults may be due to defective pickling, inefficient annealing, surface defects in sheet, or defects in the sheet material. It is stressed that flaws of similar appearance may derive from different causes.—A. G.

Thermal Factors Affecting Output in Sheet and Strip Galvanizing. J. Landeau. (*International Conf. on Hot Dip Galvanizing*, 1954, *Oxford Conf. Preprint No.* 8: Zinc Dev. Assoc.). The heating of a galvanizing bath must be flexible enough to maintain the temperature at 450° C. both during pauses in production and during maximum production. These requirements are considered and heat balances are presented for the galvanizing of cold sheets and hot strip.

An Italian Design for an Improved Galvanizing Furnace. A. Celli. (*International Conf. on Hot Dip Galvanizing*, 1954, *Oxford Conf. Preprint No.* 9: Zinc Dev. Assoc.). A new design of furnace is described permitting accurate temperature control even on small furnaces. Special features are the use of small high temperature combustion chambers and the absence of muffling.—A. G.

The Pre-Treatment of Tubes for Hot Dip Galvanizing. R. Haarmann. (*International Conf. on Hot Dip Galvanizing* 1954, *Oxford Conf. Preprint No.* 10: Zinc Dev. Assoc.). Methods of degreasing and descaling tubes are described. Scale may be removed mechanically, or by gaseous reduction, molten alkali, or acid attack. The problem of pickling waste is considered. Flux preparation and the drying and preheating of tubes are also described.—A. G.

Uses of Galvanized Tubes. A. Clift. (*International Conf. on Hot Dip Galvanizing*, 1954, *Oxford Conf. Preprint No.* 11: Zinc Dev. Assoc.). The uses of galvanized tubes are described. These include pipes for domestic and farm water supplies, gas piping, structures, scaffolding and heating and cooling systems.—A. G.

The Composition of Wire Galvanizing Baths. R. Souske (*International Conf. on Hot Dip Galvanizing*, 1954, *Oxford Conf. Preprint No.* 12: Zinc Dev. Assoc.). A study has been made of factors increasing the corrosion resistance of galvanized wires. The addition of aluminium improves the adhesion of the zinc coating while cadmium, apart from compensating for the loss in weight due to aluminium, improves corrosion resistance provided the wire is not redrawn.—A. G.

A New Continuous Process for Wire Galvanizing. L. Cazzaniga. (*International Conf. on Hot Dip Galvanizing*, 1954, *Oxford Conf. Preprint No.* 13: Zinc Dev. Assoc.). By utilizing the Joule effect to heat the wire, the need for an annealing bath or furnace is eliminated. The process has a low power consumption with a very high output. When using electrolytic zinc, tests on the galvanized wire gave excellent results.

The Sources and Control of Dross Formation in Hot Dip Galvanizing. S. A. Hiscock. (*International Conf. on Hot Dip Galvanizing*, 1954, *Oxford Conf. Preprint No.* 14, Zinc Dev. Assoc.). Up to 20% of the zinc in a bath may be removed as dross. The reaction mechanisms in 'wet' and 'dry' galvanizing have been studied in relation to the three sources of dross formation, namely, reaction between pickle and steel or flux and steel to form iron salts, and reaction between steel and molten zinc to form zinc–iron alloys. The results enable the major source of dross in a given plant to be detected and it can be predicted whether a particular modification would be economically justified.—A. G.

The Galvanizing of Threaded Parts. A. Gordet. (*International Conf. on Hot Dip Galvanizing*, 1954, *Oxford Conf. Preprint No.* 15, Zinc Dev. Assoc.). Trials to determine the conditions which will produce a deposit satisfying public service specifications are described. Uniformity of coating of threaded parts is only achieved by centrifuging after hot dipping.—A. G.

The Galvanizing of Tubes. H. Bablik. (*Mét. Constr. Mécan.*, 1954, **86**, May, 433–439; June, 531–535). The preparation of the surface galvanizing and the most suitable type of flux are discussed. The influence of the silicon content of the base metal on the efficacy of the galvanizing process is considered and photomicrographs of zinc coatings on base metals with different silicon contents are shown. The influence of the time of immersion and speed of removal from the bath on the thickness of the zinc coating is discussed.—B. G. B.

Tin Immersion Coatings. C. F. Gurnham. (*Products Finishing*, 1954, **18**, June, 74–92). Adherent deposits of tin can be obtained by immersion in a heated solution of tin salts. Operational details are given and the characteristics of deposits on steel, copper, and aluminium are discussed.—A. D. H.

Pushbutton Water Demineralization Accelerates Tinplate Production. J. K. Sargent and J. W. Stewart. (*Steel*, 1954, **134**, June 7, 114–120). The arrangement is described whereby two men operate an automatic system that turns out 7,000,000 gallons of clarified and 1,000.000 gallons of demineralized water per day.—D. L. C. P.

Engineering Metal Finish—Methods, Materials Command Equal Stature. R. J. Deisenroth. (*Steel*, 1954, **135**, July 19, 115–121). The coating of metal furniture for protection and appearance is described. An Epon resin primer and a finish enamel are applied to the parts on a moving conveyor which takes the articles through the necessary processes. Details of the coatings are given.—D. L. C. P.

How to Finish Metal Products by Vacuum Metallizing. J. G. Seiter. (*Products Finishing*, 1954, **18**, May, 38–48). After phosphating and lacquering, the parts are loaded on racks and moved into the vacuum chamber in which the pressure is reduced to 0·5 micron. To coat with aluminium, small aluminium staples are hung from an array of coils of tungsten wire filaments inside the chamber which are connected to electrodes. The aluminium melts *in vacuo* at 1200° F. and spreads over the tungsten; it is then "flashed"

at about 1800° F. and forms a coating on the parts and the inside of the chamber.—R. A. R.

Spraywelding—A Modern Hard Facing Technique. S. M. Holgate. (*Electroplating*, 1954, **7**, June, 239–245). A process to produce a surface layer which is resistant to corrosion and abrasion by building up a sprayed coating of a Ni–Cr–B alloy and fusing the deposit at 600° C. is described. New or worn cylindrical parts ¼ in. to 5 in. in dia. can be treated.

Rocker Arms Wearproofed in Quantity. (*Steel*, 1954, **134**, June 21, 138). The application and properties of a nickel-base hard-surfacing alloy for motor engine fuel pump rocker arms are described. The process involves grit blasting the part, then spraying on and fusing the alloy.

Coating with Mastics. R. B. Seymour and R. H. Steiner. (*Chem. Eng.*, 1954, **61**, May, 232–242). The wide field of application of asphaltic mastics for protecting steel against attack by many chemicals up to 150° F. is surveyed. The behaviour of coatings towards 116 common chemicals at various concentrations and temperatures is shown diagrammatically.—T. E. D.

Defects in Vitreous-Enamelled Iron Castings. E. R. Evans. (*Inst. Brit. Found.*,: *Paper No.* 1096, 1954: *Foundry Trade J.*, 1954, **97**, Oct. 7, 421–425, ; Oct. 14, 451–457). The defects responsible for the rejection of vitreous-enamelled cast-iron components are summarized and the reasons for their occurrence are discussed. Particular attention is paid to blisters, pin-holes, and black specks which are the result of gas evolution from the iron-enamel interface.—B. C. W.

POWDER METALLURGY

Powder Metallurgy and Its Very Varied Possibilities in Production. R. Meyer. (*Usine Nouvelle*, 1954, Spring Issue, 33–49). Several operations, that are specific to powder metallurgy, are described. They are sintering by means of a liquid phase, compression at an elevated temperature, and infiltration, in which a refractory framework is impregnated by a low melting point metal. There are two aspects to powder metallurgy, one of them providing a means of synthesizing materials. It makes possible the production of pure metals with a high melting point, *e.g.*, tungsten and molybdenum, pseudo-alloys, *i.e.*, of non-alloying constituents such as Fe–Cu, Wo–Ag, Mo–Ag and Ag–Ni, alloys with a carbide, boride or nitride base, which can be very hard and very heat resistant, cermet refractories, diamond impregnated cutting tools, intimate metal-plastic mixtures. Powder metallurgy is also used as a means of forming parts, the agglomerate formed by compression maintaining its shape after sintering.—T. E. D.

Practical and Theoretical Aspects of the Hot Pressing of Refractory Oxides. P. Murray, E. P. Rodgers, and A. E. Williams. (*Trans. Brit. Ceram. Soc.*, 1954, **53**, Aug., 474–503). The authors report an investigation on the hot (up to 2000° C.) pressing of several refractory oxides. Pure oxide compacts of high bulk density could be obtained. The process is also discussed from a theoretical standpoint, in relation to the plastic flow theories of sintering.—D. L. C. P.

Experimental Iron Carbonyl Powders. F. E. Joumot, jun., and L. Muldawer. (*Acta Met.*, 1954, **2**, May, 513–519). The line broadening due to strain and crystallite size has been measured by a special technique to separate the two effects using carbonyl iron powder. Annealing was found to cause a reduction in both lattice parameter and strain. The strain recovery is almost complete at 350° C. The cause of the initial distortion is discussed.—A. D. H.

A Fundamental Investigation of the Mechanism of Sintering. E. B. Allison and P. Murray. (*Acta Met.*, 1954, **2**, 487–512). The authors present data on the sintering of fluorides and the results are discussed in terms of the plastic flow theory of sintering.—A. D. H.

The Production and Utilization of Iron Powders in India. V. Aravamuthan. (*Eastern Metals Rev.*, 1953, **6**, Feb. 2, 125–126, 128). The production of iron powder by reducing iron oxides with hydrogen by decomposition of iron carbonyl, and by electrolytic deposition are considered with reference to possible Indian manufacture.—B. G. B.

Production of Largest Cemented Carbide Parts at Carboloy Plant. (*Indust. Heating*, 1954, **21**, June, 1104–1108, 1116). A description is given of a new 220-ton press for forming parts weighing up to 4000 lb. made of carbide powders. Electric heating coils, surrounded by water cooling tubes, are lowered over the mould containing the powder; these can heat the compact up to 1300°–1500° C. The press and furnace controls are such that the hot pressed parts have a very uniform structure.—R. A. R.

Effect of Temperature on Decarburization. J. O. Edström and S. E. Erikson. (*Jernkontorets Ann.*, 1954, **138**, (7), 414–422). [In Swedish]. Using Ficks' first law for the diffusion of the atoms of an element in solid solution and applying this to an iron-carbon alloy, an expression was evolved to show the temperature-dependence of the decarburization rate. Laboratory experiments with iron powder confirmed that this formula can be used to calculate the temperature range giving optimum conditions for decarburization of an iron powder containing cementite.—G. G. K.

PROPERTIES AND TESTS

200-Ton Universal Testing Machine. (*Engineer*, 1954, **198**, Aug. 27, 291–293). This article describes a 200-ton capacity universal horizontal testing machine designed by W. and T. Avery, Ltd. The machine has been supplied, together with a large selection of holders and clamps, for tensile testing of many forms of equipment such as chains, ropes, etc., as well as for the normal run of compression and transverse tests on bars, and rolled specimens.—M. D. J. B.

The Development of Methods for Studying the Strength of Metals and Alloys. J. Grandvoinnet. (*Rev. Gén. Méc.*, 1954, **38**, Jan., 1–7; Feb., 66–71; Apr., 111–118; July, 243–250). A survey is made of the wide variety of methods used to study the strength of metals and alloys. The selection of methods for testing are discussed and the tests are considered under three headings: Impact, fatigue, and hardness. The basic principles of a number of methods used for testing in each group are explained. The measurement of the modulus of elasticity with mechanical extensometers, strain gauges or by indirect dynamic methods such as those based on the measurement of transverse vibrations in the sample or time of vibration are discussed. The use of magnetic, X-ray, gamma ray, and ultrasonic methods for the examination of metals is described.—B. G. B.

Plates Subjected to Compression or Tension and to Simultaneous Transverse Load. O. Pettersson. (*I.V.A.*, 1954, **25** (2), 78–82). [In English]. The deflection w at any point on a symmetrically loaded and constructed plate can be calculated from:

$$w = \frac{1 \pm a\dfrac{N}{Ncr}}{1 \pm \dfrac{N}{Ncr}} w_t$$

in which w_t is the deflection due to the transverse load, N the axial force, N_{cr} the corresponding Euler buckling load, a is a dimensionless coefficient, and the + − signs indicate tensile or compressive axial stress respectively.—G. G. K.

Studies on the Relation Between Some Static and Dynamic Properties of Carbon Steels Under Different Thermal Treatments. S. Chatterjee and G. P. Chatterjee. (*Trans. Indian Inst. Met.*, 1952, **6**, 193–202). The authors have investigated the relation between the three values A (the area under the stress-strain curve in the tensile test), P where

$$P = \tfrac{1}{5}\left(\frac{\text{max. stress lb./sq. in.}}{1000} + 6 \times \text{reduction in area \%}\right)$$

and z = Izod value for various plain carbon steels after different thermal treatments. The following results were obtained: (1) For plain carbon steels with normal heat-treatments, other than tempering after water quenching, $z = \alpha e^{\beta P}$ where α and β are constants depending on the heat-treatment. (2) For annealing and normalizing treatments where $P > 70$, $Z > 10$ ft. lb. for hypoeutectoid carbon steels; with low carbon contents Z increases much more rapidly for a given change in P. (3) The Z values are in general more sensitive to varying heat-treatments than P values. (4) The relation between A and Z is $Z = \alpha e^{-\beta A}$.—D. H.

Elastic and Plastic Bending of Oil-hardened Spring Wires. W. Neuhaus. (*Draht, German ed.*, 1954, **5**, June, 203–207; July, 262–267). Elastic and plastic bending properties are defined by reference to bending theory, an instrument for the testing of spring wires is described, and the results of investigations of the properties are described. The principal

conclusions were: (1) Residual austenite, pre-critical pearlite and ferrite traces are detrimental to the attainment of a high elastic limit and low permanent set. (2) To achieve highest quality the carbon content should exceed 0·90%.—J. G. W.

Comparison of the Repeated Impact Value of Several Hollow-Shank Steels. M. Uchiyama and F. Seki. (*Tetsu to Hagane*, 1952, **38**, Feb., 91–95). [In Japanese]. Studies were made on plain carbon, Ni–Cr, Cr–Mo, Ni–Cr–Mo, Mn–Cr–Mo, Mn–Cr–Mo–V, high-carbon–chromium, and high-carbon, high-Cr–Mo steels, using Charpy and Matsumura testing machines. Of the plain carbon steels, 0·55% C steel gave the best results, but Ni–Cr–Mo steel was the most suitable. (14 references).—K. E. J.

Effects of Anodic Surcharging on the Behaviour of Some Plain Carbon Steel. G. P. Chatterjee, K. C. Som, and R. Ganguly. (*Trans. Indian Inst. Met.*, 1952, **6**, 233–242). The paper deals with the effects of the anodic surcharging on the hardness of a plain carbon steel and the effects of ageing the surcharged steels for varying times. The following results were obtained: (1) Plain carbon steel surcharged with oxygen showed a decrease in Rockwell B hardness values. (2) On ageing after various periods of surcharging, the hardness values reached a maximum then a minimum and finally approached a steady value. (3) The maximum and minimum values were lower the longer the period of surcharging. (4) Decarburization occurred on surcharging.

Some Studies on Hardness and Work-Hardenabilities of Metals and Alloys. G. P. Chatterjee. (*Trans. Indian Inst. Met.*, 1952, **6**, 219–232). The author discusses hardness in general terms and develops the concept of hardness in terms of work done per unit volume of deformation. The values of hardness derived by this method compare well with corresponding Brinell hardness values.—D. H.

The Slip Process During Yield Point Deformation. E. W. Hart. (*Acta Met.*, 1954, **2**, May, 416–418). The effect of the increased yield stress on the production of a slip burst is discussed and qualitative application is made to the yield point phenomenon.—A. D. H.

Conditions for the Initiation and Progress of Brittle and Deformation Fractures on the Basis of the Properties of Dislocations. A. Kochendörfer. (*Arch. Eisenhüttenwesen*, 1954, **25**, July-Aug., 351–372). The processes which lead to brittle and tough fractures are described with reference to the static and dynamic properties of dislocations. It is shown that certain arrays of dislocations are unstable and under stress can transform to holes which then serve as Griffiths cracks for the propagation of fracture. The conditions under which the repulsion between dislocations can be overcome and brittle fracture then arise, and the influences of deformation rate, temperature and strain ageing on the transition from brittle to tough fracture are discussed. The treatment is first applied to single crystals and then extended to polycrystalline materials.—J. P.

An Apparatus for the Accurate Measurement of Internal Friction. J. R. Pattison. (*Rev. Sci. Instruments*, 1954, **25**, May, 490–496). This electronic instrument is actuated by a voltage-time decay form, the decay following an exponential law. The accuracy, with a logarithmic decrement δ below 7×10^{-3}, is at least 0·25% for a single reading; for $\delta = 7 \times 10^{-2}$ the accuracy is 2·5% for a single reading. The frequency range extends from 100 counts/sec. to 100 kc./sec. A detailed description of the apparatus is given.—L. D. H.

New Non-Destructive Method for the Determination of Superficial Residual Stresses. L. Hausseghy and H. Martinod. (*Recherche Aéronaut.*, 1954, Jan.-Feb., 43–50). A new method is described for the accurate determination of Hertzian hardness, which is linked with the superficial elastic limit. The use of the values obtained for determining superficial residual stresses is studied. Results are given and discussed in detail.—T. E. D.

Dependence of Mechanical Properties of Forgings on Local Strain. P. M. Cook. (*J. Iron Steel Inst.*, 1955, **179**, Mar., 250–252). [This issue].

Effect of Wire Drawing on the True Stress-Strain Curve. M. S. Mitra and M. G. Fontana. (*Trans. Indian Inst. Met.*, 1952, **6**, 170–192). The effect of wire drawing on the four types of steel (18%-Cr 8%-Ni, 18%-Cr 12%-Ni, 17%-Cr, and 0·20%-C) has been determined. The following conclusions were reached: (1) The effect of prestrain on the plastic zone of the true stress-strain curves is that they remain parallel after various prestrains by drawing. (2) With all four steels the effect of prestrain by drawing is identical with that of tension until the prestrain reaches the value of necking strain of the undeformed steel. (4) The position of the critical prestrain (necking strain of the undeformed steel) is confirmed by the effects of the prestrain on true strain at fracture.—D. H.

Some Observations on the Deformation in Stainless Steels. M. S. Mitra and M. G. Fontana. (*Trans. Indian Inst. Met.*, 1952, **6**, 137–149). Metallographic and X-ray methods have been used to study the effect of cold deformation on the 18/8, 18/12, and 17%-Cr. types of stainless steel. Metallographic methods using etch figures and deformation lines showed that, with the austenitic steels, deformation took place by slip along the (111) planes. With the 18/8 steel, X-ray investigations indicated that preferred orientation of [111] and [100] directions parallel to the direction of drawing took place. In the case of the 17%-Cr steel, the preferred orientation was [110] parallel to the fibre axis.—D. H.

Measuring Loads in Wires—Two Simple Devices to Ensure Accuracy in Prestressing. N. W. B. Clarke. (*Engineering*, 1954, **177**, June 25, 812–815). The author describes two devices for measuring the tension in wires for prestressed concrete. The devices, which are simple and can be used by semi-skilled operations, approach the accuracy of the proving ring.—M. D. J. B.

Fatigue Testing Fixtures. T. R. Breunich. (*Product Eng.*, 1954, **25**, June, 200–205). Types of fixture for materials testing and simulated service testing, design information and applications are described. Care is necessary in the preparation of the specimen to prevent premature failure due to stress concentrations. Dynamic test fixtures must be designed to ensure that the proper force is applied and that service conditions are actually duplicated. Experimental static tests are often necessary before a proper method of fatigue loading can be determined.—A. M. F.

Fatigue Strength of Screw Threads. J. E. Field. (*Engineer*, 1954, **198**, July 23, 123–124). The author describes a series of investigations on the fatigue strengths of screw threads recently carried out at the Mechanical Engineering Research Laboratory.—M. D. J. B.

Study of "Understressing" by the Progressive Stress Method. M. Davin. (*Rev. Gén. Mic.*, 1954, **38**, June, 179–184). The use of the Prot method of fatigue testing to investigate the effect of understressing on fatigue resistance is described. The results obtained are discussed and compared with those found for normal specimens using constant stress methods and the Prot method.—B. G. B.

Effect of Ceramic Coatings on Fatigue Strength of Metal. W. J. Plankenhorn. (*J. Amer. Ceram. Soc.*, 1954, **37**, June, 281–288). A series of tests was conducted to determine the effect of porcelain enamels and ceramic coatings on the endurance limit and fatigue life of ingot iron components subjected to flexure. A comparison of results for the metal alone and for the coated metal showed that ceramic coatings noticeably improved the fatigue strength, and also the fatigue life at stresses above the endurance limit.—D. L. C. P.

Fatigue Tests of Steel Speciments Prepared for Metallizing. R. C. Miller, jun. and A. W. Brunot. (*Welding J.*, 1954, **33**, June, 275s–279s). The effect of several surface preparation procedures on the fatigue resistance of steel shafts was determined. The rough threading method was found to be the least damaging. Electrode roughening and metal spray bonding were found to be less desirable, though rough-threading showed a slight improvement in fatigue strength, grooving and roughening gave a higher deposit bond strength.—U. E.

Relationship Between Micro- and Macro-Hardness. W. Schultze and L. Schimmer. (*Arch. Eisenhüttenwesen*, 1954, **25**, July-Aug., 337–339). Vickers hardness measurements have been made on steel specimens (VDH 280–850) with loads from 10 to 3000 g. When the length of the diagonal of the impression was plotted against the load, on double logarithmic paper, the points fitted a straight line from which the Meyer exponent could be calculated. Since there was no tendency for the line to change direction at high loads, it was assumed that it could be extrapolated to the usual Vickers testing loads. The Vickers hardness calculated in this way agreed well with that measured. The Meyer exponent is thus independent of load and depends only on the material. Values found in the micro-load range can therefore be

employed in the range where, because of the asymptotic course of the hardness-load curve, it is not possible to observe a load dependence.—J. P.

Measurement of the Microhardness of High-Melting Carbides. A. E. Koval'skiĭ and L. A. Kanova. (*Zavodskaya Laboratoriya*, 1950, **16**, (11), 1362–1365). [In Russian]. The effects of work-hardening during polishing, and the conditions of microhardness testing, on the determination of the microhardness of alloys containing carbides of titanium, zirconium, molybdenum, vanadium, and tungsten were investigated.

Relationship Between Micro- and Macro-Hardness of Ferrite and Aluminium Crystallites. A. Schepers and W. Bartholome. (*Arch. Eisenhüttenwesen*, 1954, **25**, July-Aug., 341–343). The Meyer exponent has been determined in the micro-load range on ferrite and aluminium crystallites, and employed to calculate the macro-hardness. For ferrous metals, the calculated hardness agrees with that measured, but with aluminium, the small value of the Mayer exponent makes extrapolation inaccurate.—J. P.

Classification of Steels by Means of Hardenability Tests. J. Gonin and G. de Smet. (*Usine Nouvelle*, 1954, Spring Issue, 101–109). Hardenability tests were performed and the results examined in conjunction with other tests on a number of steels with a view to enabling steels to be classified. The Jominy test for temperability is described, and Jominy curves, temperability curves, and dilatometric analyses are given.—T. E. D.

Determination of Plasticity Parameters of Metals by the Cone-Indentation Method. G. P. Zaĭtsev and S. A. Smolich. (*Zavodskaya Laboratoriya*, 1950, **16**, (11), 1355–1361). [In Russian]. A method of assessing the plasticity of a metal by conical indentations on a polished surface of the metal is described. An equation is given relating the load on the cone, the diameter of the indentation and two plasticity parameters, one of which has the dimensions of stress the other being dimensionless. The equation holds when the angle of the cone is sufficiently large and when not much slip takes place over the surface of the cone.—S. K.

Cold Rolling and Annealing of Safety Razor Blade Steel. S. Kashiba and T. Kuno. (*Tetsu to Hagane*, 1952, **38**, Mar., 159–161). [In Japanese]. Investigations were made on a steel containing 1·16% C, 0·23% Si, 0·4% Mn, and 0·47% Cr. The hardness decreased as the annealing temperature was raised to 725° C. With cold reductions of 18–35%, the hardness showed a minimum at annealing temperatures of 500–725° C. The hardness was hardly affected by annealing times between 3 and 6 hr. and the cementite size was only affected as the annealing temperature approached the A_1 point.—K. E. J.

Magnetic and Electromagnetic Sorting of Semi-finished Steel and Mass-Produced Articles. F. Förster. (*Arch. Eisenhüttenwesen*, 1954, **25**, July-Aug., 383–391). Apparatus and procedures are described for sorting steel and non-ferrous components according to composition, heat-treatment, and structure.—J. P.

Increasing the Initial Permeability of Low Silicon-Iron and Aluminium-Iron Alloys by Oxidizing Annealing at Low Temperature. H. Fahlenbrach and E. Houdremont. (*Arch. Eisenhüttenwesen*, 1954, **25**, July-Aug., 377–381). The initial permeability of 2·5–4·5% silicon–iron and 3–5% aluminium–iron alloys, in strip or sheet form, was markedly increased by prolonged annealing at temperatures between 400° and 800° C. The effect is attributed to the removal of carbon by the oxidizing atmosphere. The most suitable conditions for various thicknesses of material are given.—J. P.

Replacing Non-Ferrous Metals by Non-Magnetic Steel. V. Kořán. (*Slévárenství*, 1954, **2**, (6), 173–174). [In Czech]. Heavy brass parts holding the steel sheets in the stators of large alternators have been replaced by an austenitic manganese steel.—P. F.

The Rapid Non-Destructive Determination of Sheet Anisotrophy by the Coercive Force Micro-Pole Method. F. Forster and G. Zizelmann. (*Z. Metallkunde*, 1954, **45**, Apr., 245–249). An apparatus is described for the determination of the anisotrophy of sheets by measurement of coercive force in different directions. The apparatus is compact, and does not involve damage to the work. A 'micro-pole' is produced in the specimen by means of a pointed permanent magnet, and the tangential component of the residual magnetism, which is proportional to the coercive force, is measured on the instrument described; hence the anisotrophy of the material is determined.—L. D. H.

Research on Electrical Properties of Iron Grid Materials. M. Okamoto and A. Okada. (*Tetsu to Hagane*, 1952, **38**, Mar., 127–132). [In Japanese]. Studies were made of the specific resistance and its temperature coefficient for material containing 3% C and 3–6% Si; the influence of graphite, silicon and the metallographic structure, are discussed. The graphitization of iron normally causes increases in both the resistance and its temperature coefficient.—K. E. J.

Non-Destructive Testing by Means of Gamma Rays. O. Lamm. (*I.V.A.*, 1954, **25**, (4), 170–171). [In English]. A summary is given of a report on Swedish grant-aided work in this sphere, completed in 1952 and using mainly $cobalt_{60}$.

Resonant Scattering of Gamma-Rays in ^{63}Cu and ^{56}Fe. K. Ilakovac. (*Proc. Phys. Soc.*, 1954, **A, 67**, July 1, 601–607).

Creep Rupture Properties and Structural Changes in Carbon and Low Alloy Steels. A. B. Wilder, E. F. Ketterer, and D. B. Collyer. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**, : *J. Met.*, 1954, **6**, June, 764–772). The authors have studied the behaviour of 59 carbon and low-alloy steels after long periods of exposure (10,000–34,000 hr.) at 480° and 565° C., investigating the creep rupture properties of the parent metal and the microstructure of deposited weld beads with particular reference to graphitization. The results are tabulated and the behaviour of the different steels is discussed.—G. F.

Causes of Variable Creep Strength in Basic O.H. Carbon Steel. W. E. Bardgett and M. G. Gemmill. (*J. Iron Steel Inst.*, 1955, **179**, Mar., 211–219). [This issue].

Cast Alloy Tops for Hot Spots. E. A. Schoefer. (*Steel*, 1954, **134**, May 24, 122–125). Compositions and properties of standard U.S. heat-resisting Cr–Ni steel castings are set out. Examples quoted include soaking-pit cover parts, furnace dampers, skid rails, sheet and bar annealing equipment, and metallic recuperators.—D. L. C. P.

A New Carbide-Base Cermet Containing TiC, TiB_2 and CoSi. H. M. Greenhouse, R. F. Stoops, and T. S. Shevlin. (*J. Amer. Ceram. Soc.*, 1954, **37**, May, 203–206). The development of the new material and its properties are described. The oxidation-resistance up to 2200° F., the and stress-sustaining characteristics are excellent.—D. L. C. P.

Silicon-Base Cermets and Related Observations. B. C. Weber and P. S. Hessinger. (*J. Amer. Ceram. Soc.*, 1954, **37**, June, 267–272). Chemical reactions involving silicon in various atmospheres and at elevated temperatures were studied in connection with the usability of silicon in cermet bodies for high temperature applications in aircraft power plants. Cermets involving silicon, TiO_2, TiC, and titanium silicides were investigated, including oxidation resistance tests. The specimens used were prepared by slip-casting.

Ceramics for Aircraft Propulsion Systems. L. D. Richardson. (*Amer. Ceram. Soc. Bull.*, 1954, **33**, May, 135–137). A brief history is given of research and development in the following spheres of high temperature application: (1) Oxide-base bodies; (2) intermetallic compound-base bodies; (3) graphite and graphite-base bodies; and (4) ceramic coatings.—D. L. C. P.

On a New Heat-Brittleness in Steel. N. Yamanaka and K. Sato. (*Tetsu to Hagane*, 1952, **38**, May, 321–327). [In Japanese]. A new type of heat-brittleness was distinguished; it is liable to occur when the steel bath is deoxidized by an inadequate amount of aluminium and more than the critical amount of Al_2O_3 is retained, the austenite grain size at 925° C. being very small. (11 references).

The Properties of Some Heat-Resisting Steels after Long-Time Heating at High Temperature. M. Tagaya and S. Isa. (*Tetsu to Hagane*, 1952, **38**, Apr., 203–206). [In Japanese]. The results are given of the effects on Fe–Cr and Fe–Cr–Al steels of heating at temperatures from 500–1200° C. for periods up to several days *in vacuo*, and in hydrogen and nitrogen atmospheres. Tensile strengths, elongation, bending properties, electrical resistance, and grain size were examined. The deterioration in properties was most marked in steels containing aluminium, particularly in a nitrogen atmosphere, as the result of diffusion and the precipitation of aluminium nitride.—K. E. J.

Study on Heat-Resisting Steels for Gas Turbine Blades. K. Deguchi. (*Tetsu to Hagane*, 1952, **38**, Feb., 95–101; Mar., 133–137). [In Japanese]. Various physical, mechanical, forging, and creep tests are reported on high-carbon

Cr–Ni austenitic steel, Tinidur, high Cr–Ni–V steel, and other alloys, the effects of 0·15% of nitrogen being also investigated. For turbine blades, WH42B, LCN-155 and Timken 16/25/6/ Cr–Ni–Mo alloy (with added nitrogen) are recommended. Practical problems are the scarcity of nickel and cobalt, the procedure for adding nitrogen, and forging difficulties.—K. E. J.

Behaviour of Arsenic on Heating Steel. Y. Nakagawa. (*Tetsu to Hagane*, 1952, **38**, Apr., 228–234). [In Japanese]. The heating of steels containing arsenic caused a concentration of arsenic on the surface, under the scale, in oxidizing atmospheres, but not *in vacuo* or reducing atmospheres. It was caused by selective oxidation, and existed mainly as Fe–As compounds, being detrimental to finishing processes. K. E. J.

Strength of Cast Alloys at 1200° F. J. R. Lane. (*Product Eng.*, 1954, **25**, June, 207, 209, 211). Tabulated test results of seventeen alloys of molybdenum, tungsten, titanium, vanadium, manganese, and niobium are given. Properties include room temperature tensile, creep rupture at 1200° F. and mechanical properties of forged alloys.—A. M. F.

Study on High Pressure Vessel Steels. T. Saito. (*Tetsu to Hagane*, 1952, **38**, Apr., 220–227; Sept., 654–659). [In Japanese]. Various steels were tested at temperatures up to 600° C. and pressures up to 800 atm., under conditions simulating those of the Claude and Casale ammonia synthesis processes. Nitrogen attack was more severe than that of hydrogen, and increased with NH_3 concentration. Chromium steel showed cracks, but steel with $> 5\%$ Cr showed improved resistance.—K. E. J.

Influence of Oxygen on the Properties of Iron and Steel (III). T. Saito. (*Tetsu to Hagane*, 1952, **38**, Jan., 18–25). [In Japanese]. Investigation as to whether the effects of oxygen on grain size and hardenability were caused by inclusions or FeO were made with steel containing aluminium and alumina. The influence of oxygen was attributed to non-metallic inclusions; it is therefore necessary to prevent oxidation of the molten steel bath and to separate deoxidized products when using deoxidizers. (13 references).—K. E. J.

METALLOGRAPHY

Solubility of Hydrogen in Iron–Carbon Alloys. B. G. Davies and T. Evans. (*Inst. Brit. Found.*, 1954, June 22–25, *Paper No.* 1102). The effects of temperature and pressure on the equilibrium solubility of hydrogen in Fe–C alloys containing up to 3·4% C have been determined between 600° and 1000° C. Within the range of pressure and temperature studied, Sievert's Law is valid for all the alloys, and this enabled the measured solubilities to be corrected to a standard pressure of 1 atm. The equilibrium solubilities did not vary appreciably with carbon content but showed a minimum at about 0·55% C and a maximum between 1·3 and 1·8% C depending on temperature. The cast iron with 3·4% C showed an increased solubility as graphitization occurred.—B. C. W.

Solubility of Nitrogen in *a*-Iron. H. U. Åström and G. Borelius. (*Acta Met.*, 1954, **2**, May, 547–549). The discrepancy between previous determinations of nitrogen by mechanical relaxation and isothermal calorimetry are discussed. Further experiments using an improved relaxation technique are described. The results are shown to be in fair agreement with previous relaxation results.—A. D. H.

The Diffusion of Carbon in Alpha Iron. W. R. Thomas and G. M. Leak. (*Phil. Mag.*, 1954, **45**, Sept., 986–987). Measurements of the diffusion coefficient were made in the range 0–100° C. by observing the change in internal friction or damping capacity caused by carbon in solution. The careful preparation of the specimens is described. The results, which agree substantially with those of Wert, give $D_0 = 3{\cdot}16 \times 10^{-2}$ sq. cm./sec.$^{-1}$ and $Q = 20{,}400$ cal.—K. E. J.

The Calculation of Heats of Formation of Binary Alloys. J. H. O. Varley. (*Phil. Mag.*, 1954, **45**, Sept., 887–916). A theoretical treatment for calculating heats of formation is put forward, based on the assumption that the free electrons in the alloy exist in two sets of energy levels associated with the potential fields of the ions of the two elements. Fair agreement between calculated and experimental values is found, particularly when the elements are not too far removed in the periodic system. The theory offers explanations for magnetic behaviour, relative valency and widths of Fermi bands. (17 references).—K. E. J.

An Fe-Cr-Mo-Ni Sigma Phase. A. G. Allten. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**: *J. Met.*, 1954, **6**, Aug., 904–905). By X-ray diffraction and metallographic means, the author has identified a quaternary Fe–Cr–Mo–Ni σ phase in a steel of the following composition: 0·06% C, 1·26% Mn, 0·38% Si, 21·15% Ni, 18·72% Cr, 3·07% W, and 9·14% Mo. The observed characteristics of the phase are given, and it is found to obey the empirical rules derived from compositions of binary and ternary σ phases.—G. F.

The Metastability of Austenite in an 18/8 Cr-Ni Alloy. B. Cina. (*J. Iron Steel Inst.*, 1955, **179**, Mar., 230–240). [This issue].

Investigation of the Equilibrium Diagram of Fe–As–C System. H. Sawamura, T. Mori, T. Fukase, and S. Yamamoto. (*Tetsu to Hagane*, 1952, **38**, Apr., 234–238). [In Japanese]. Continuations of previous work are reported, including the long-time annealing of many ternary alloys. The invariant points and solubility planes were determined, and the system completed, including the gamma loop, ferrite solidus line, and the solubility limit of Fe_2As in ferrite.—K. E. J.

Activity of Silicon in Liquid Fe–Si and Fe–C–Si Alloys. J. Chipman, J. C. Fulton, N. Gokcen, and G. R. Gaskey, jun. (*Acta Met.*, 1954, **2**, May, 439–449). Results of studies on the solubility of graphite and silicon carbide in molten iron containing up to 20–24% Si are given. The distribution of silicon between these solutions and molten silver were measured at 1200–1690° C. Using the above data and already published results; the activity of silicon in binary and ternary solutions was determined at temperatures of 1420–1700° C.

The Ordering of Atoms in the Chi-Phase of the Iron–Chromium–Molybdenum System. J. S. Kasper. (*Acta Met.*, 1954, **2**, May 1, 456–461). The crystal structure of the chi-phase in an alloy containing 56% Fe, 17% Cr and 27% Mo has been studied by X-ray and neutron diffraction. The structure is an ordered α-Mn type.—A. D. H.

Precipitation out of Dual Solid Solutions of Carbon and Nitrogen in Alpha-Iron. C. Wert. (*Acta Met.*, 1954, **2**, May, 361–367). Precipitation of dual solutions of carbon and nitrogen in pure iron has been studied by internal friction and magnetic coercive force measurements. The effect of either of the elements is to speed up the ageing of the one with the slower rate to equal that of the faster. The structure of the precipitate so formed is unknown but it may be a carbonitride.—A. D. H.

CORROSION

Corrosion Committee's Long-Term Tests, Series D. S. Alfort, P. Bane, G. Ekwall, G. Tengstrand and P. Å. Wallgren. (*I.V.A.*, 1954, **25**, (4), 149–163). [In Swedish]. Detailed results are presented of the five-year exposure in a harbour atmosphere of steel samples painted with 30μ coats of various paints, the object being to determine paint durability. Test procedure, sources of error and their elimination, and the characteristics of the paints employed are discussed.—G. G. K.

Inhibition and Activation. J. Frasch. (*Métaux-Corrosion-Indust.*, 1954, **29**, May, 216–224). Factors influencing the inhibition or activation of corrosion are considered in detail. The electrochemical concept of corrosion is discussed in relation to the corrosion of iron. Cathodic and anodic polarization and the inhibition of corrosion by these factors are described. Examples of the practical use of inhibitors in minimizing corrosion are given.—B. G. B.

The Tendency of the Solution Pressure of Metals to Change Locally under Low Stresses. P. Koch. (*Metalloberfläche*, 1954, **8**, Jan., A1–A7; Mar., A37–A41; May, A74–A79). A method, using very sensitive instruments, was developed by which the electropotential at small areas (7 sq. mm.) along the surface of stressed metal specimens immersed in a corrosive medium could be measured. Differences in potential were established which were due to slip in small local zones in the specimens. Further tests showed that the observed effects on the solution pressure were not the result of an increase in temperature due to slip.—R. A. R.

In Corrosion Testing, Humidity Cabinets Don't Tell the Whole Story. L. Schlossberg. (*Steel*, 1954, **135**, July 12, 114–118). Various methods of accelerated corrosion testing

are considered. Examples illustrate how the results of artificial tests are difficult to reproduce, and are misleading when used for predicting results of atmospheric exposure tests.—D. L. C. P.

Corrosion or Protection at Gaps in Metallic Coatings on Steel. U. R. Evans. (*Trans. Inst. Metal Finishing*, 1954, **31**, Advance Copy No. 8). The electrochemical state at a gap in a coating may be anodic or cathodic according to the nature of the coating and the environment. The causes of variable polarity are analysed and the effects observed at discontinuities in both anodic and cathodic coatings are discussed with reference to tin, zinc and aluminium coatings on steel.—A. D. H.

The Scope and Development of Cathodic Protection. K. A. Spencer and D. A. Lewis. (*Corrosion Prevention and Control*, 1954, **1**, Mar., 15–21; Apr., 77–82; May, 155–158, 165; June, 221–223). This history of cathodic protection is traced and the principles of corrosion and the mechanism of cathodic protection are introduced. Its applications to various types of structures, such as tank bottoms, gas holders, and ships, are discussed on the basis of general principles and past experience. Cathodic protection equipment, including instruments, electric supply equipment, and anodes are described. (18 references).—L. E. W.

Cathodic Protection of Internal Surfaces. H. M. Powell. (*Corrosion Prevention and Control*, 1954, **1**, May, 166–167, 181). The conditions under which the corrosion of internal surfaces can occur and the failure of coatings to provide protection are briefly discussed. The successful application of galvanic anodes is considered with particular reference to the insertion of a resistor in the anode circuit, the coating of the anode with a metallic sheath of less corrodible nature or with insulating material, and the use of platinum and high-silicon iron anodes.—L. E. W.

Application of Cathodic Corrosion Protection. W. Thury. (*Maschinenwelt u. Elektrotechnik*, 1954, **9**, July, 198–201). A survey is given of present practice with some applications of cathodic protection against corrosion. Two methods, one using galvanic action with a soluble anode, and the other with an applied current, are discussed. (15 references).

The Corrosion of Metals in Soils. (*Corrosion Prevention and Control*, 1954, **1**, May, 163–165). The preliminary findings from an investigation by the U.S. Bureau of Standards on the corrosion of representative pipe materials in soils are briefly discussed. Copper corrodes appreciably in soils high in sulphides, but low-copper brasses are very resistant. Some steels containing high percentages of chromium possess good corrosion resistance but small amounts of chromium, and also nickel and molybdenum, have little effect. The effect of environment on the rate of corrosion is considered. The Bureau's studies have enabled the corrosion of iron, steel, copper, lead, and zinc to be expressed by a single empirical equation [not given] in which one constant is the initial rate of corrosion while the other expresses the progress of corrosion with time.—L. E. W.

The Reading Accuracy When Measuring Corrosion and Thickness by Means of Ultrasonic Pulses. A. Lutsch. (*Z.V.d.I.*, 1954, **96**, Aug. 11, 773–777). The use of ultrasonics for the qualitative and quantitative study of surface corrosion and sheet thickness is described, and the accuracy of measurement quoted from investigations.—J. G. W.

The Oxidation of Iron at 175 to 350°C. D. E. Davies, U. R. Evans, and J. N. Agar. (*Proc. Roy. Soc.*, 1954, **A, 225**, Sept. 22, 443–462). Five methods of study were employed, hydrogen-reduced specimens being always used. Oxidation of iron powder is never isothermal. Up to 250° C. α-Fe_2O_3 appears, while above 250° C. a duplex film containing also Fe_3O_4 appears. The growth law is parabolic above 325° C., but logarithmic below: the mechanisms can be explained in terms of migration through the film or oxygen leakage through discontinuities respectively. (59 references).

Electron Optical Study of Oxidation of High Purity Iron at Low Oxygen Pressures. E. A. Gulbransen, W. R. McMillan, and K. F. Andrew. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**,: *J. Met.*, 1954, **6**, Sept., 1027–1035). The authors have made a preliminary study of the initial stages of oxidation of iron at high temperatures, by electron-microscope examination of samples of annealed pure iron, electrolytically polished and oxidized between 650° and 850° C. at low pressures. Initial oxidation is non-uniform and is related to the sub-structure of the metal grains. Thermodynamic equilibria are discussed and kinetic-theory predictions on the rate of collision of oxygen with the iron surface are considered.

Effect of the Composition of Gas-Turbine Alloys on Resistance to Scaling and Vanadium Pentoxide Attack. G. T. Harris, H. C. Child, and J. A. Kerr. (*J. Iron Steel Inst.*, 1955, **179**, Mar., 241–248). [This issue].

ANALYSIS

A Linear Motion X-Ray Spectrometer. H. P. Hanson and H. W. Schrader. (*Rev. Sci. Instruments*, 1954, **25**, May, 422–423). A single crystal X-ray spectrometer is described in which the Bragg angle is changed by a linear rather than angular movement of the crystal.—L. D. H.

Precision Laboratory Standards of Mass and Laboratory Weights. (*U.S. Nat. Bur. Standards*, 1954, *Circular* 547, Section 1).

A Method for the Spectrographic Analysis of Alloys Having Special Compositions. K. V. Chinnappa. (*Trans. Indian Inst. Met.*, 1952, **6**, 342–343). A modified method is described which yields more accurate results than are normally obtained in the spectrographic analysis of alloys of such composition that they are not adequately covered by a standard sample.

A Simplified Procedure for the Determination of Index Point and Index Line in the Step-Filter Technique of Spectrographic Analysis. K. V. Chinnappa. (*Trans. Indian Inst. Met.*, 1952, **6**, 339–341). A simplified accurate procedure is described for the determination of *Ko* (index point) and *Km* (index line) in the step-filter technique of spectrographic analysis.—D. H.

Investigations Concerning Light Sources for Spectrum Analysis. V—High Voltage Spectrographic Spark Source with Electronic Control. A Bardócz. (*Acta Technica*, 1954, **8**, (1–2), 99–107). [In English]. A circuit consisting of a fixed controlling spark gap and a thyratron tube is employed to control the high voltage spark source. Particulars of the circuit are given together with some characteristic voltage curves.—R. A. R.

Spectrophotometric Determination of Silicon in Steel and Cast Iron. P. Enghag. (*Jernkontorets Ann.*, 1954, **138**, (7), 404–413). [In Swedish]. A modification of Hill's method was used to study the influence of temperature on the formation rate and stability of the silicomolybdic acid solution, whilst the reaction is so slow at room temperature as to require some 20 min. for the extinction to attain its maximum, only 2 min. are required at 100° C. At this temperature, however, the colour transformation rate of the acid solution increases considerably, resulting in a bleaching effect.

Precision Determination of Low Concentrations of Carbon in Metals. L. P. Pepkowitz and W. D. Moak. (*Analy. Chem.*, 1954, **26**, June, 1022–1025). The method for the determination of less than 0·01% carbon in metals uses a simplified apparatus consisting of a commercially available high-frequency heating combustion unit and a simple differential freeze-out technique for the isolation of CO_2 which eliminates the necessity for a high vacuum. Carbon, with a mean deviation of $\pm$ 0·0002%, was determined in several nonferrous metals. A routine precision of $\pm$ 0·0002% was obtained for carbon in standard steel samples with concentrations as low as 0·0028%. Lowest limit of detection is 0·002 mg. or 0·0002% on a 1-g. sample.—T. E. D.

Photometric Determination of Low Silicon Contents in Steel. H. Wölk. (*Arch. Eisenhüttenwesen*, 1954, **25**, July-Aug., 333–336). Comparison of the gravimetric and the photometric silicomolybdate and molybdenum blue methods has indicated the applicability of the latter for the estimation of silicon contents below 0·01% in unalloyed steels. The preparation of the calibration curves and the methods employed for steel analysis are described in detail. The procedure can be carried out in 40–45 min. and the accuracy is $\pm$ 0·0005%.—J. P.

Direct-Reading Spectrographic Determination of Phosphorus in Steel and Iron Ore. C. G. Carlsson and L. Danielsson. (*Jernkontorets Ann.*, 1954, **138**, (7), 383–403: *Iron Steel Inst. Translation Series* No. 498, 1955). [In Swedish]. A detailed study was made of the direct determination of phosphorus using a medium-size quartz spectroscope equipped with electron multiplier tubes. The exit slits had to be accurately adjusted and a new type of slit holder evaluated. A triggered low-voltage A.C. spark gave high sensitivity, while a simple and cheap photoelectric recording circuit evolved by Naish

and Ramsden, suitable for determining one element, was found satisfactory. Phosphorus contents down to 0·005% were determined in steel and ore, with a standard deviation of less than ± 5%. The same analysis curve can be used for all carbon steels.—G. G. K.

Precise Determination of Iron and of Iron Oxides when Present Together. W. Kangro and G. Wiebke. (*Arch. Eisenhüttenwesen*, 1954, **25**, July-Aug., 327–331). A method is described for the determination of iron, and indirectly, of iron oxides. This depends on the internal electrolysis of a ferric halide solution between a silver anode and a platinum cathode. The weight of iron in solution is assessed from the weight of silver halide on the cathode. The procedures for estimating iron or iron oxides alone or together are given.

Rapid Electrochemical Method for Testing of Alloy Steels and Ferrous Alloys. E. Fitzer. (*Arch. Eisenhüttenwesen*, 1954, **25**, July-Aug., 321–326). Procedures are described for carrying out rapid electrochemical spot tests for iron, chromium, nickel, molybdenum, manganese, silicon, cobalt, tunsgsten, copper, and titanium. The results are qualitative but can give a semi-quantitative assessment of the concentrations of alloy elements. Suitable apparatus for carrying out the tests is described.—J. P.

A Rapid Method for Determination of Total FeO in Acid Slag. S. Maekawa and Y. Kikuchi. (*Tetsu to Hagane*, 1952, **38**, Jan., 31–35). [In Japanese]. The Gakushin method has the disadvantage of requiring fusion in a nickel crucible. Methods based on direct solution in acid were therefore investigated. The values obtained by a Mitsubishi method are slightly high or low according to the type of slag, though the results of Gakushin and Muroran methods agree. High results are due to chromium, and low results to the fact that only active (free) FeO is estimated.—K. E. J.

Photocolorimetric Determination of MnO, Al_2O_3 and P_2O_5 in Open-Hearth Slags. V. I. Zhuravskaya. (*Zavodskaya Laboratoriya*, 1950, **16**, (11), 1302–1304). [In Russian]. Procedures for the rapid photocolorimetric determination of MnO, Al_2O_3 and P_2O_5 in open-hearth slags using a Davydov-type appratus are described, and results obtained are shown to agree well with those of gravimetric and volumetric methods. The MnO determination is based on the persulphate-silver method, that of Al_2O_3 on the formation of a red compound with a special reagent, and that of P_2O_5 on the formation of molybdenum blue in the reduction of phosphomolybdate by bivalent iron salts and sodium sulphate.—S. K.

Rapid Determination of Phosphorus in Agglomerate. Yu. M. Usatenko and P. A. Bulakhova. (*Zavodskaya Laboratoriya*, 1950, **16**, (11), 1393–1394). [In Russian]. The following procedure is recommended for the rapid determination of phosphorus in ores and all types of agglomerate. A 1-g. sample is fused with soda at 1000° C. and the mass is treated with the equivalent of 25 ml. of conc. HCl. The agglomerate is completely dissolved by warming the solution, which is then evaporated to a thick paste. This is filtered at 70° C. after the addition of 0·1% gelatine solution, and the phosphorus in the filtrate is precipitated as phosphomolybdate which is then determined in the usual way.—S. K.

HISTORICAL

Iron Making in the Black Country, Past and Present. W. K. V. Gale. (*J. Junior Inst. Eng.*, 1954, **64**, May, 234–248). Although the mineral resources of the Black Country are exhausted, the iron trade has not left the area altogether. Pig iron is still made in two towns, wrought iron in three towns, and steel in three towns. The history of the industry is surveyed, and the technological developments which have wholly or partly originated in the district are described.

The Reconstruction of a Blast-Furnace Built in 1813. A. Schleicher. (*Acta Technica*, 1954, **8**, (3–4), 425–433). [In German]. A rectangular blast-furnace built between 1810 and 1813 at Diosgyör, Garadnatal, Hungary, has been carefully reconstructed to its original dimensions. Drawings and photographs are presented.—R. A. R.

BOOK NOTICES

EDWARDS, A. B., "*Textures of the Ore Minerals and Their Significance.*" With a Foreword by B. E. Jacka. Second edition. 8vo, pp. xiii + 242. Illustrated. Melbourne, 1954: Australasian Institute of Mining and Metallurgy (Inc.). (Price 60*s.* Australian).

During the two decades preceding the publication of the first edition of this work in 1947, much original work on the interpretation of ore mineral textures had appeared in the various technical journals. To this literature the author had made many valuable contributions. Though several books were available on the microscopic determination of ore minerals, there was no up-to-date English text on the interpretation of their textures and inter-relations. As one might expect, Dr. Austin Edwards has assembled this material in a concise and easily readable form.

The first edition soon went out of print. Though other authors have been attracted to this field, Edwards' work is still outstanding and petrologists in many countries will be grateful to him and to the Australian Institute of Mining and Metallurgy for this second edition. In its presentation it follows the successful pattern of the first edition, though new data and examples have been added and the opportunity has been taken to eliminate minor errors. The new edition includes a chapter on the texture of smelter products.

Here then is an authoritative work describing the textures of the native metals, the zonal and banded textures observed in the oxide and sulphide ores and those developed by deformation and replacement. Solid solutions in native and in both oxide and sulphur-bearing minerals are treated very thoroughly. The chapter on the application of the foregoing to ore geology, perhaps the crux of the work, makes one feel in sympathy with Oliver Twist; the same is true of the chapter on ore dressing. The only serious criticism concerns the last two chapters on the transparent gangue minerals and on smelter products; both are too short. The illustrations are excellent and the references quite adequate. The work should be stimulating to metallographers as well as to mineralogists.—W. DAVIES.

LANG, RUTH (Editor). "*Laboratory and Workshop Notes*, 1950–1952." A third selection reprinted from the *Journal of Scientific Instruments*, compiled for the Institute of Physics. 8vo, pp. xii + 280. Illustrated. London, 1954: Edward Arnold (Publishers) Ltd. (Price 30*s.*).

These notes, which total 118, as usual cover a very wide field, so that few laboratory workers will fail to find something of interest and value among them. They are presented under the following headings: Mechanical Design; Laboratory Tools: Methods and Hints; Optical and Thermal Devices and Techniques, and Infra-red Spectrometry; Devices for Liquids and Gases; Vacuum Devices and Techniques; Electrical Devices and Techniques. Items of metallurgical interest which catch the eye are: An apparatus for creep testing under conditions of constant stress; a device for attachment to a microscope stage so that a specified field on a specimen may be located quickly and accurately; an interferometer for calibrating extensometers; and, useful points in connection with electrolytic polishing. On the more general side, the following may be cited: A glassblower's knife of cemented carbide material; equipment for handling radioactive substances; a simple goniometer for the study of crystal surfaces; a simple timing device for use with camera recordings of oscilloscope traces, and a machine for rapidly processing such recordings; and an article on voltage stabilization.

The good standard of the earlier volumes in this series is maintained, and the present one may be recommended as an extremely useful and interesting acquisition for those who make and use physical apparatus.—A. R. BAILEY.

LIPS, E. M. H. "*Engineering Metallurgy.*" With a Foreword by G. V. Stabler. Published in Dutch and English; English translation by Mrs. A. H. Teves-Acly. 8vo, pp. xv + 250. Illustrated. Eindhoven, Holland, 1954: Philips Technical Library; Distributors for United Kingdom and Eire: Cleaver Hume Press, Ltd.; for U.S.A. and Canada: Elsevier Press, Inc. (Price 32*s.* 6*d.*).

This book gives useful accounts of various aspects of metallurgy which are important to the engineer, such as mechanical properties, corrosion, phase diagrams, ferrous and non-ferrous alloys, heat-treatment, and the working and joining of metals. Although it has clearly been the author's intention to simplify the general treatment of phase diagrams, it has turned out to be far too superficial, as has the chapter on the 'Corrosion of Metals and Alloys' (consisting of less than six pages).

The writing is in clear and simple language, and in general the technical details appear satisfactory. The author has made an apparent effort to set out the matter in the way in which he thinks it would best be assimilated by an engineer. There is no question that an engineer or an engineering student would profit from reading the book. The production is of good standard and there are numerous clear illustrations. However, the scope of the book is by no means an uncommon one, and the treatment is not so remarkable as to warrant translation from the Dutch.

A. R. BAILEY.

STOCKING, GEORGE W. "*Basing Point Pricing and Regional Development.*" A Case Study of the Iron and Steel Industry. 8vo, pp. ix + 274. Illustrated. Chapel Hill, U.S.A., 1954: University of North Carolina Press. (Price 52*s.*).

Basing-point pricing tended to keep United States steel prices high, claims the author, who produced this study in response to a request for an analysis of the effect of basing point pricing on the economic growth of the Southern States. The system's main characteristic is that all sellers, wherever located, quote delivered prices made up of a base price plus a rail freight charge. A single basing-point system, known as "Pittsburgh Plus," was used by the U.S. steel industry up to 1924, when the Federal Trade Commission ordered the price leader—United States Steel Corporation—to abandon it. Its effect on Southern States consumers was disadvantageous, for it increased the cost of their steel, thereby restricting their market. A multiple basing-point system operated from 1924, but since all basing-points were still in the North (basic prices being lowest at Pittsburgh), Southern fabricators benefited only slightly. This position continued until 1938, when Birmingham (Ala.) was made a basing-point and prices at all basing-points were for the most part made identical. Southern consumers then bought indifferently from both North and South. On 7th July, 1948, the United States Steel Corporation announced an f.o.b. basis, and other steel companies immediately followed suit. The result was that customers turned to nearby producers (thus cutting the length of hauls) and insisted on the cheapest method of transport.

For over half a century the Pittsburgh-Youngstown district, as the centre of the basing-point system, has been built up to supply a national, not merely a local market; now, however, steelmakers recognize that f.o.b. pricing is reversing this trend, and in 1948 Mr. Benjamin Fairless went so far as to say that the United States Steel Corporation might have to build plants in other areas—certainly no more at Pittsburgh.—J. C. JENKINS.

NEW PUBLICATIONS

AHRENS, L. H. "*Quantitative Spectrochemical Analysis of Silicates.*" A scheme of quantitative DC arc analysis of the silicate minerals, rocks, soils, and meteorites. 8vo, pp. 120. Illustrated. London, 1954: Pergamon Press, Ltd. (Price 25*s.*)

AMERICAN FOUNDRYMEN'S SOCIETY. "*The Cupola and Its Operation.*" Second edition. 8vo, pp. 300. Illustrated. Chicago, Illinois, 1954: The Society. (Price: members $6.00; others $9.50)

AMERICAN SOCIETY FOR METALS. "*Fatigue.*" By the following authors: Thomas J. Dolan, B. J. Lazan, and Oscar J. Horger. A Series of educational lectures on Fatigue presented to members of the A.S.M. during the thirty-fifth National Metal Congress and Exposition, Cleveland, October 19 to 23, 1953. 8vo, pp. [iii +] 121. Illustrated. Cleveland, Ohio, 1954: The Society. (Price 27*s.*)

AMERICAN SOCIETY FOR METALS. "*Metals Handbook.*" 1954 Supplement, edited by Taylor Lymen. La. 8vo, pp. 184. Illustrated. Cleveland, Ohio, 1954: The Society. (Price: members $4; non-members $5)

"*Directory of Welding and Fabricating Equipment.*" Section I. '*Metal-Arc Welding Electrodes.*" Reprinted from "Welding and Metal Fabrication." La. 4to, pp. 35. London [1954]: The Louis Cassier Co., Ltd. (Price 3*s.* 6*d.*)

EPSTEIN, GEORGE. "*Adhesive Bonding of Metals.*" Sm. 8vo, pp. ix + 218. Illustrated. New York, 1954: Reinhold Publishing Corp.; London: Chapman and Hall, Ltd. (Price $2.95; 24*s.*)

HODGMAN, CHARLES D. (Editor). "*Handbook of Chemistry and Physics: A Ready Reference Book of Chemical and Physical Data.*" Thirty-fifth edition. 8vo, pp. xii + 3163. Cleveland, Ohio, 1953: Chemical Rubber Publishing Co.

HOYT, S. L. "*Metal Properties.*" Sponsored by the Metals Engineering Handbook Board of the American Society of Mechanical Engineers. (ASME Handbook.) 4to, pp. 440. New York, Toronto, London, 1954: McGraw Hill Book Co. (Price $8.80)

IMPERIAL CHEMICAL INDUSTRIES, LTD. "'*Cassel*' *Manual of Heat-Treatment and Case-Hardening.*" Pp. 216. Illustrated. London, 1954: The Company. (Price 15*s.*)

"*Jahrbuch der Oberflächentechnik, 1955.*" 11. Auflage. Gesamtbearbeitung, W. Wiederholt. 8vo, pp. 904. Illustrated. Berlin-Grunewald, 1955: Metall-Verlag, G.m.b.H. (Price DM 15.–)

"*Korrosionsschutz im Stahlbau,*" (Veröffentlichungen des Deutschen Stahlbau-Verbandes, H.1.) 8vo, pp. 76. Köln, 1954: Stahlbau-Verlags G.m.b.H. (Price DM 7.50)

KULBATSCHNEY, I. G. "*Maschinelle Ausrustung von Walzwerken.*" 8vo, pp. 1034. Berlin, 1954: Verlag Technik. (Price DM 75.–)

MOLLOY, E. (Editor). "*Electroplating and Corrosion Prevention.*" 8vo, pp. x + 278. Illustrated. London, 1954: George Newnes, Ltd. (Price 18*s.*)

POCHWISNEW, A. N., W. S. ABRAMOW, N. I. KRASSAWZEW. and N. K. LEONIDOW. "*Der Hochofenbetrieb.*" (Übersetzung aus dem Russischen.) 8vo, pp. 843. Berlin, 1954: Verlag Technik. (Price DM 66.–)

"*Pocket Book of Tables.*" Eighth edition. Sm. 8vo, pp. 56. London, 1954: "The Ironmonger." (Price 3*s.* 6*d.*)

H. SCHELLER. "*Einführung in die angewandte spektrochemische Analyse.*" 8vo, pp. 137. Illustrated. Berlin, 1953: VEB Verlag Technik. (Price DM 18.–)

SHANK, M. E. "*A Critical Survey of Brittle Fracture in Carbon Plate Steel Structures other than Ships.*" 4to, pp. 48. New York, 1954: Welding Research Council. (Price 16*s.*)

"*Smithsonian Physical Tables.*" (Smithsonian Miscellaneous Collections Volume 120, (whole Volume)). Ninth revised edition, prepared by William Elmer Forsythe. 8vo, pp. vi + 827. Illustrated. City of Washington, 1954: The Smithsonian Institution. (Price 77*s.* 7*d.*)

"*Tafeln zur Ermittlung der Vickershärte.*" Neu bearb. von Kurt Meyer. 8vo, pp. 56. Berlin, 1954: Beuth-Vertrieb. (Price DM 4.50)

VAND, VLADIMIR, and RAY PEPINSKY. "*The Statistical Approach to X-Ray Structure Analysis.*" La. 8vo, pp. xvi + 98. State College, Pa., 1953 : Pennsylvania State University.

"*Vorträge des Berg- und Hüttenmännischen Tages* 1953: *Metallformung.*" 8vo, pp. 74. Illustrated. Berlin, 1954: Akademie-Verlag. (Price DM 7.–)

WEHRLI, HANS-RUDOLF. "*Die Eisenerzeugung der Schweiz im zweiten Weltkrieg.*" (Dissertation der Universität Bern, 1952.) 8vo, pp. vi + 200. Schwarzenbach (SG), 1954: Druck Franz Renggli. (Price 21*s.* 6*d.*)

"*World's Non-Ferrous Smelters and Refineries,* 1954." Fifth edition. Edited by H. G. Cordero, Foreign Editor, "The Metal Bulletin." 8vo, pp. 432. Illustrated. London, 1954: Quin Press, Ltd. (Price 40*s.*)

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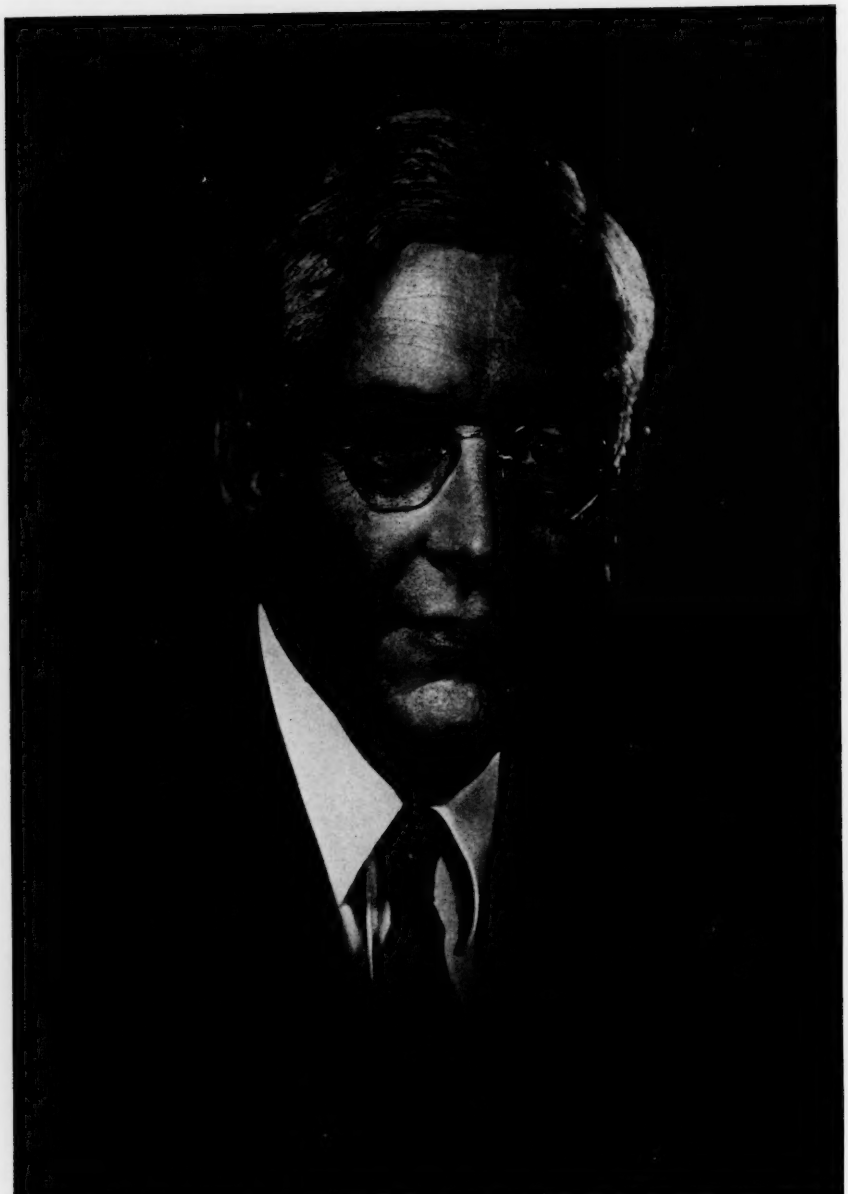
Dr. Chipman became Assistant Professor of Chemistry at the Georgia School of Technology in 1926; he left in 1929 to become a Research Engineer at the University of Michigan. He joined the staff of the Massachusetts Institute of Technology in 1937 as Professor of Process Metallurgy, and took up his present appointment as Head of the Department of Metallurgy in 1946.

The recipient in 1934 of the Howe Medal of the American Society for Metals, and in 1939 of the Hunt Award of the American Institute of Mining and Metallurgical Engineers, Dr. Chipman was elected President of the former Society for the Session 1951–52. He has been a Member of The Iron and Steel Institute since 1938, and this year he has been awarded the Bessemer Gold Medal of the Institute in recognition of his distinguished contributions to the knowledge of the physical chemistry of steelmaking.



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Bessemer Medallist, 1955